## Pine Natural Regeneration

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# THE PLANTATION CONVERSION DEMONSTRATION AT THE CROSSETT EXPERIMENTAL FOREST—IMPLICATIONS FOR CONVERTING STANDS FROM EVEN-AGED TO UNEVEN-AGED STRUCTURE

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**Abstract**—In the absence of replicated studies, we used a case study demonstration to illustrate converting a 26-year-old even-aged loblolly pine (*Pinus taeda* L.) plantation to uneven-aged structure. Unreplicated treatments included maintaining even-aged structure through low thinning (thinning from below) to a residual basal area of 80 square feet per acre, and two methods of converting to uneven-aged structure-one using the volume control guiding diameter limit method, and the other using the BDq method of structural regulation. Over 12 years, all three treatments had a periodic annual increment of over 90 square feet per acre in both total merchantable and sawtimber cubic volume; all three treatments also maintained annual sawtimber volume growth rates of 90-100 square feet per acre, 450-600 board feet per acre Doyle rule, and 600-750 board feet per acre International ¼-inch rule. In all volume increment measurements, the even-aged treatment exceeded the volume control method, which exceeded the BDq method. Conversely, the BDq method was the only treatment in which adequate pine regeneration was established and making acceptable development; regeneration development in the volume control treatment was marginal, and it was unacceptable in the even-aged treatment. After 12 years, residual basal area levels exceeded 60, 75, and 100 square feet per acre in the BDq, volume control, and even-aged treatments, respectively. To increase the reliable development of regeneration in these treatments, lower residual basal areas should be considered.

## INTRODUCTION

Over the past two decades, interest has grown in converting even-aged stands to uneven-aged structure. A public forest land manager or a private forest landowner might consider this conversion because uneven-aged stands have more heterogeneous within-stand habitat and structural attributes than plantations. Examples include enhanced vegetation or wildlife species diversity, or a more gradual flow of higher-value products than plantations typically provide.

Conversion of uneven-aged to even-aged conditions can be accomplished very quickly—either by clearcutting and planting, or by harvesting to a seed-tree or shelterwood residual basal area (RBA) and encouraging the development of natural regeneration from seed that fall from the residual stand. Conversion from even-aged to uneven-aged conditions takes more time, because trees in the submerchantable size classes are usually not present in sufficient numbers. Development of an uneven-aged diameter distribution may take several cutting cycles, during which time it will be desirable also to maintain adequate volume production.

However, scientific evidence supporting conversion of even-aged to uneven-aged stands, especially in plantations, is limited. Most studies and demonstrations of uneven-aged silviculture in southern pines have focused on recovery from understocked conditions rather than conversion of fully-stocked even-aged structure; this is the case for the Good Farm Forestry Forty and especially the Poor Farm Forestry Forty at the Crossett Experimental Forest in southern Arkansas (Reynolds and others 1984), the Hope Farm Forestry Demonstration at Hope, AR (Farrar and others 1984a), and the Mississippi State Farm Forestry Forties on the Starr Memorial Forest near Starkville, MS (Farrar and others 1989).

The best example of converting even-aged plantations to uneven-aged structure is the Dauerwald, established in the late 19th and early 20th century in southeastern Germany in the state of Anhalt. Stands managed using the Dauerwald were Scotch pine (*Pinus sylvestris* L.) plantations on relatively poor sites with sandy soils, limited vegetative competition, and abundant naturally-occurring regeneration. Those conditions promoted the establishment and development success of regeneration in the smaller size classes, and over time that led to the success of the new method (Troup 1928, Troup 1952).

However, no current replicated research studies to convert even-aged plantations to uneven-aged structure are available for any of the major southern pines in the southern U.S. Therefore, non-replicated demonstrations are an alternative source of data on the mechanics of plantation conversions. One such study is underway in the upper West Gulf Coastal Plain for loblolly (*P. taeda* L.) pine

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plantations is the Plantation Conversion Demonstration at the Crossett Experimental Forest.

Our objectives have been to investigate the conversion of even-aged plantations to uneven-aged structure. In the demonstration, two methods of regulating uneven-stands and one method of maintaining even-aged conditions are compared.

## METHODS

The demonstration was established in 1980 by the junior author in a 26-year-old loblolly pine plantation located in Compartment 61 of the Crossett Experimental Forest, located in Ashley County approximately 7 miles south of Crossett, AR. Site index for loblolly pine in the study area is 95 feet (base age 50 years). Soils are of the Providence and Bude series, loamy to silt loam in texture, and are poorly drained to moderately well drained.

Three plots, each approximately four acres in size, were located within the plantation. One of three treatments was applied randomly to each plot:

1) Even-aged 80 RBA—-Thinned periodically from below, if operable, to leave 80 square feet per acre of residual basal area.
2) Uneven-aged volume control-guiding diameter limit method (VCGDL)-—Using the volume control-guiding diameter limit method of regulating uneven-aged stands developed by Reynolds (Reynolds and others 1984), stands were operationally treated through periodic cutting until before-cut stand volumes sup ported about 75 square feet per acre of basal area, 2000 cubic feet per acre of total merchantable cubic volume, and 7000 board feet Doyle per acre.
3) Uneven-aged BDq method (BDq)—-The stand was regulated through cutting-cycle harvests using a BDq target stand as the marking guide, where the target stand is set at a residual basal area (the "B" in the BDq acronym) of 60 square feet per acre, a maximum retained d.b.h. (D) of 22", and a q (1-inch classes) of 1.2 (Baker and others 1996).

All three plots were burned by prescription for brush control and hazard reduction during the 1979-80 dormant season prior to study installation. Since then the 80 RBA treatment was burned by prescription during dormant seasons of 1983-84, 1986-87, and 1989-90. All three plots also were treated with herbicides to control unwanted hardwood vegetation; this treatment consisted of basal stem injection of hardwoods 1" d.b.h. and larger using Tordon 101R (picloram plus 2,4-D) in March 1981. In September 1991, a second hardwood control treatment was applied to the uneven-aged plots, consisting of 16 oz. of Arsenal AC (imazapyr) applied using a broadcast sprayer mounted on an articulated rubber-tired skidder.

Data were reported for 12 growing seasons—-summer 1980 through summer 1991. Harvest activity, and inventories to quantify harvest, were conducted during February-March 1981 as the demo was installed, and during the winters of 1983-84 when all plots were harvested, 1986-87 when only the uneven-aged plots were harvested, and 1991-92 when harvest activity occurred on all plots. Inventories of overstory trees were based on 100-percent tallies of all trees 3.6 inches d.b.h. and larger, which were recorded by 1-inch diameter classes and as either pine or hardwood. Overstory plot cruises were conducted, and stands were marked and cut, in each of the dormant seasons of 1980-81, 1983-84, 1986-87, and 1991-92. Marking tallies were also 100-percent tallies of marked trees, recorded by 1-inch d.b.h. classes. After-cut stand conditions were determined by subtracting the marking tally from the cruise tally. For all plots, stand tables were prepared from cruise data using local volume tables.

Regeneration data were tallied as pine or hardwood by 1-inch d.b.h. classes from 0 inches to 3 inches, based on the following classification:

1) 0-inch class—all trees greater than 6 inches in height up to 4.5 feet in height, and if greater than 4.5 feet in height, = 0.5 inches d.b.h.
2) 1-inch class—trees 0.6 inches = d.b.h. = 1.5 inches
3) 2-inch class—trees 1.6 inches = d.b.h. = 2.5 inches
4) 3-inch class—trees 2.6 inches = d.b.h. = 3.5 inches

In the 1980-81 and 1983-84 measurements, regeneration was tallied on 50 0.01-acre fixed-radius plots, by species and diameter class. In the 1986-87 and the 1991-92 measurements, 100 0.001-acre fixed-radius plots (milacres) were sampled for the 0-inch class; for these, milacre stocking percentages were calculated by treatment. In addition, 50 0.01-acre fixed-radius plots were sampled for the 1-inch, 2-inch, and 3-inch classes.

Because overstory data were based on 100-percent tallies, and regeneration data were not replicated, statistical comparisons were not used. Instead, data were presented as summaries for the respective treatments.

## RESULTS

### Stand Structure over Time

The 80 RBA showed a textbook progression of stand development over time in response to thinning (figure 1). Low thinning removed largely the suppressed,

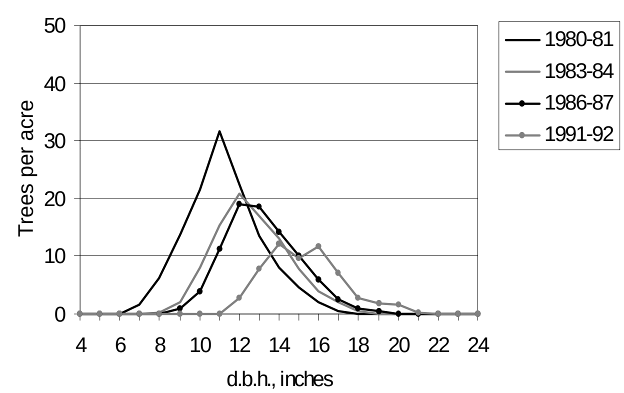


Figure 1—Diameter distribution of the pine component in the even-aged 80 RBA treatment during 1980-81, 1983-84, 1986-87, and 1991-92.

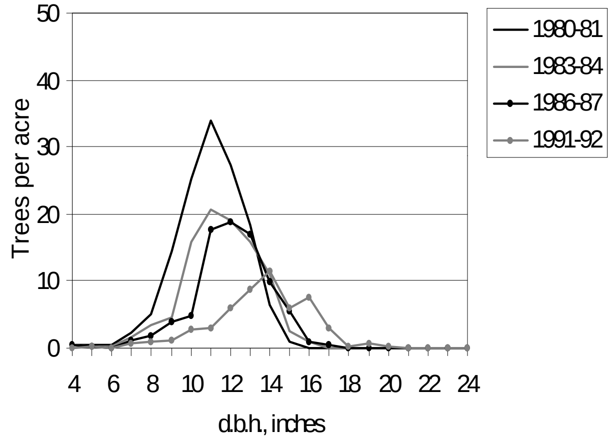


Figure 2—Diameter distribution of the pine component in the uneven-aged volume control-guiding diameter limit treatment during 1980-81, 1983-84, 1986-87, and 1991-92.

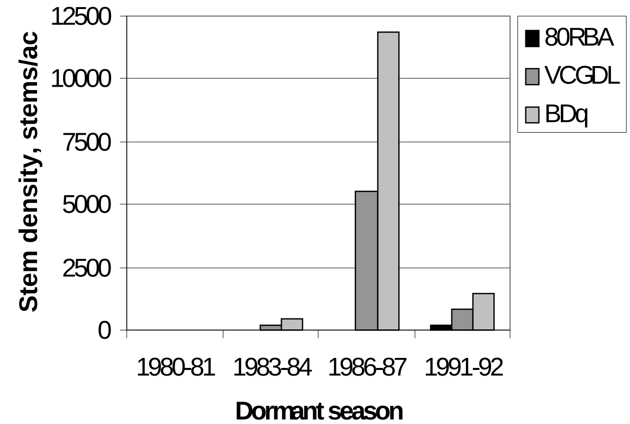


Figure 4—Pine regeneration density by treatment, 0-inch to 3-inch classes inclusive, during 1980-81, 1983-84, 1986-87, and 1991-92.

intermediate, and poorer codominant trees during each harvest. This drove the observed increase both in median diameter and in the size of the smallest trees that remain.

The VCGDL treatment showed a different pattern of residual stands over time (figure 2). Regulation in the VCGDL was done in the sawtimber classes, and the key to implementing the VCGDL method was to “cut the worst trees and leave the best” throughout the range of sawtimber diameters. As a result, there was more whittling away in the larger sawtimber diameter classes than in the low thinning of the 80 RBA treatment and less dramatic shifts in the median diameter. Also, in the VCGDL method, pulpwood-sized trees often were allowed to persist in the stand until they crossed the sawtimber size threshold; a tree’s value in board feet is 4 to 10 times greater than its corresponding pulpwood-based cubic-foot value. This resulted in less incentive to remove trees in the subsawtimber classes.

The same principle of ‘cut the worst and leave the best’ applied in the BDq method (figure 3). But where the VCGDL method encourages the forester to cut the worst and leave the best across all sawtimber diameter classes, the BDq method guides the forester to apply this principle within each merchantable diameter class. This leads to the more obvious pattern of ‘taking the top’ off the normal curve in the sawtimber component, and shaping the diameter distribution to conform more closely and more rapidly to the reverse J-shaped BDq target distribution.

## Periodic Annual Volume Increment

The 12-year periodic annual increment (PAI) for all three treatments exceeds 80 cubic feet per acre for total merchantable cubic volume, and 90 cubic feet per acre for sawtimber cubic volume (table 1). The 80 RBA treatment had the highest values for these variables, exceeding 100 cubic feet per acre annually for the 12-year period. The uneven-aged VCGDL treatment also exceeded 100 cubic feet per acre annually. The BDq treatment had the lowest PAI, falling roughly 20 percent behind the 80 RBA treatment in total merchantable cubic volume, and 13 percent less than the 80 RBA treatment in sawtimber cubic volume.

Twelve-year PAI trends for the sawtimber board foot measures were similar (table 1). All treatments exceeded

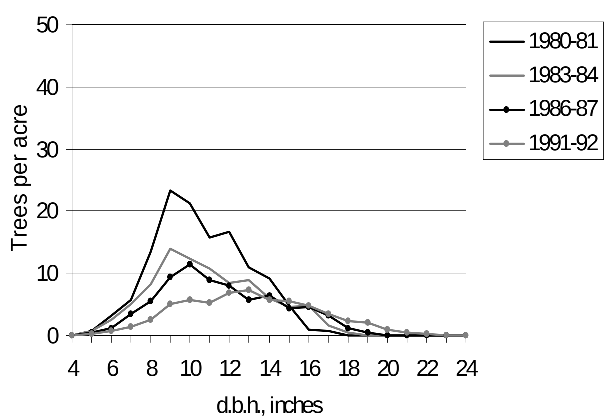


Figure 3—Diameter distribution of the pine component in the uneven-aged BDq treatment during 1980-81, 1983-84, 1986-87, and 1991-92.

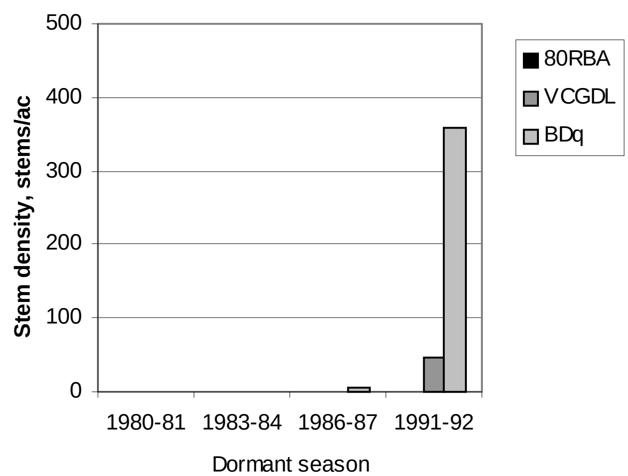


Figure 5—Pine regeneration density by treatment, 1-inch to 3-inch classes inclusive, during 1980-81, 1983-84, 1986-87, and 1991-92.

**Table 1—Periodic annual volume increment over 12 growing seasons for the three treatments. TMCV, total merchantable cubic volume; SCV, sawtimber cubic volume, Doyle, sawtimber board-foot volume under the Doyle log rule; Intl. ¼, sawtimber board-foot volume under the International ¼-inch log rule**

| | TMCV<br>$ft^3$/ac | SCV<br>$ft^3$/ac | Doyle<br>fbm/ac | Intl. ¼<br>fbm/ac |
|---|---|---|---|---|
| 80RBA | 106.3 | 108.0 | 566.8 | 716.9 |
| VCGDL | 99.7 | 103.0 | 493.7 | 675.3 |
| BDq | 84.9 | 93.6 | 465.5 | 633.0 |

**Table 2—Percentage of after-cut basal area in trees 11.6 inches d.b.h. and larger, by inventory year and treatment**

| | 1980-81<br>*percent* | 1983-84<br>*percent* | 1986-87<br>*percent* | 1991-92<br>*percent* |
|---|---|---|---|---|
| 80RBA | 53.8 | 80.8 | 88.2 | 100.0 |
| VCGDL | 50.7 | 63.7 | 74.4 | 91.1 |
| BDq | 51.4 | 60.0 | 66.2 | 79.0 |

450 board feet per acre Doyle, and 600 board feet per acre International ¼-inch rule, annually. Again, the 80 RBA treatment was best, the VCGDL treatment was intermediate, and the BDq treatment was poorest. The BDq method had roughly 18 percent less Doyle board foot volume, and 12 percent less International ¼-inch volume, than the 80 RBA treatment. However, the 12-year PAI for all three treatments exceeds the 37-year average annual production of the Good and Poor Farm Forestry Forties for these three volume variables (Guldin and Baker 1988).

## Pine Regeneration Density

The cyclical nature of pine regeneration in uneven-aged stands was readily apparent when all regeneration classes were considered (figure 4). By the 1986-87 growing season, pine regeneration density exceeded 5,000 stems per acre in both uneven-aged treatments. But over the next 6 years, those numbers dropped to slightly more than 500 stems per acre of pine regeneration. Pine regeneration did not become established in the even-aged RBA 80 treatment, and none was expected; the 3-year cyclic prescribed burn treatment destroyed most of the pine regeneration that had become established.

Examination of the 1-inch to 3-inch size classes gave a better impression of the successful development of regeneration into larger regeneration classes (figure 5). Provisional standards for acceptable regeneration (Baker and others 1996) suggest that uneven-aged stands require a minimum of 200 stems per acre of desired reproduction. By this standard, only the BDq treatment was effective in promoting development of regeneration into stems larger than 0.5 inch in diameter after 12 years.

Milacre stocking data also show the decline in numbers from 1986-87 to 1991-92 (figure 6). According to Baker and others (1996), the standard for minimum acceptable milacre stocking of desired species is 20 percent. By that standard, both uneven-aged treatments had acceptable milacre stocking in 1986-87, because the VCGDL

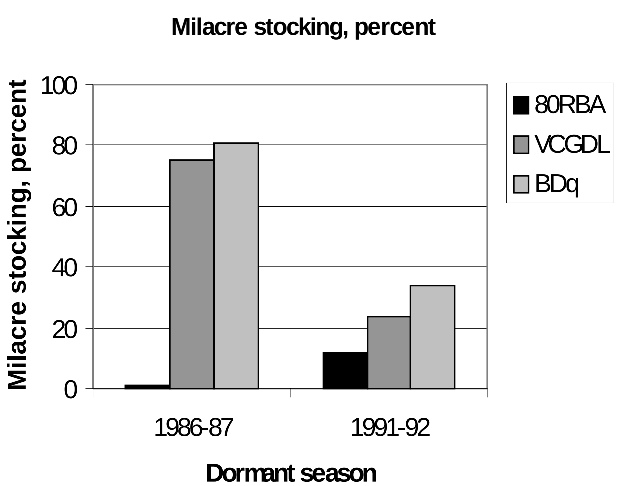


Figure 6—Milacre stocking of pine regeneration by treatment, 0-inch to 3-inch classes inclusive, during 1986-87 and 1991-92.

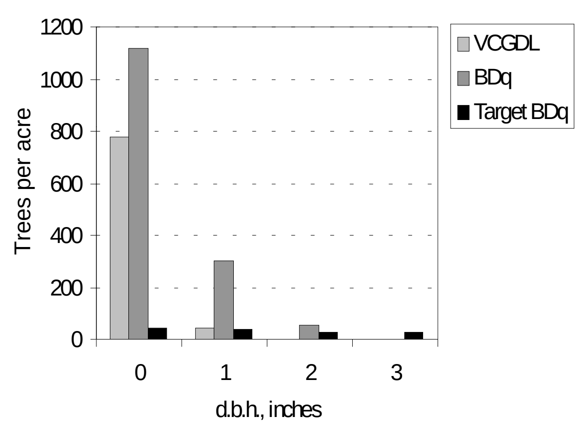


Figure 7—Regeneration density for two uneven-aged treatments compared to that expected based on the target BDq structure.

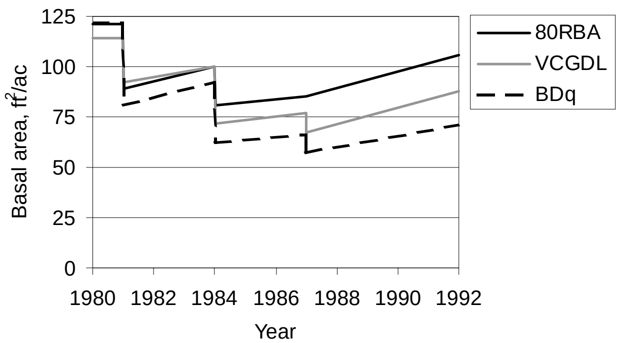


Figure 8—Basal area trends over the 12-year period by treatment.

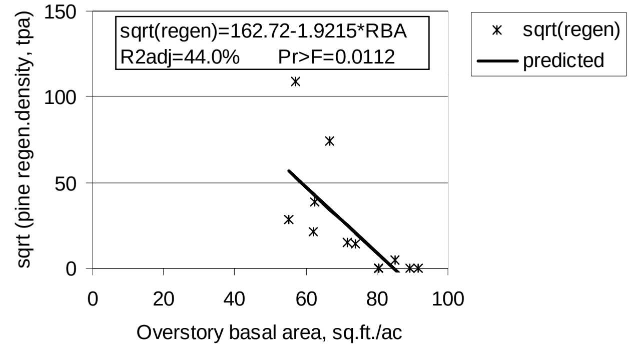


Figure 9—Relationship between before-cut basal area of trees 3.6 inches in d.b.h. and larger versus transformed regeneration density variable.

exceeded 70 percent and the BDq exceeded 80 percent. But by 1991-92, milacre stocking in both treatments had declined. At barely over 20 percent milacre stocking, the VCGDL treatment was marginal; whereas the BDq was acceptable at better than 30 percent milacre stocking.

A final way to judge whether regeneration density is adequate in uneven-aged stands is to compare observed density with that expected under the BDq target structure. The expected density can be calculated from the typical before-cut BDq parameters extended to the 0-inch, 1-inch, 2-inch, and 3-inch d.b.h. classes. Farrar (1996) suggests that the expected density derived in this way should be considered a minimum, and that two to three times that number should be present especially in the smaller size classes, since the rate of mortality of trees in the smaller size classes will be higher. In this demo, the BDq treatment is better than the VCGDL treatment in meeting or exceeding expected numbers by size class (figure 7), although neither treatment has produced adequate regeneration density in the 3-inch class after 12 years.

### Basal Area of Different Treatments

High basal area in these treatments also may have adversely affected regeneration development. The BDq treatment was the only one in which after-cut residual basal area fell below 60 square feet per acre, and it was also the only treatment in which basal area remained below 75 square feet per acre from 1984 to 1992 (figure 8). Experience with the Good and Poor Farm Forestry Forties suggests that the best compromise between overstory growth and understory development is to maintain basal area between 60 and 75 square feet per acre (Baker and others 1996, Farrar 1996). Pooling the before-cut inventory data from each treatment with regeneration density data suggested a significant inverse relationship that reinforces these observations (figure 9).

Another factor that may have affected pine regeneration development was the percentage of basal area in sawtimber. Again, experience from the Good and Poor Farm Forestry Forties and elsewhere suggests that from between two-thirds to three-quarters of the total after-cut basal area should be in the sawtimber size classes, which for those stands started with the 12-inch diameter class (Farrar and others 1984b). In these stands, the percentage of basal area in trees 11.6 inches d.b.h. and larger increased over the duration of the study, ultimately exceeding 75 percent in all treatments (table 2).

## DISCUSSION

The successful establishment and development of the desired species of regeneration is critical to the success of uneven-aged systems. By this standard, the BDq method was the only successful treatment over the 12-year conversion interval. The VCGDL treatment also exceeded these minimal standards, but only barely; if one tallied only the 1-inch and larger stems, this treatment had a stem density too low to be considered a success.

Conversion from even-aged to uneven-aged conditions is a long process. In 1986-87, both uneven-aged treatments had more than 5,000 stems per acre in the regeneration size classes. However, an additional 6 years of growth led to a prominent reduction in the number of stems in the regeneration size class, especially in the VCGDL treatment with its higher overstory basal area.

After 1987, the original planted trees and one cohort of regeneration had become established. Recruitment of a third age cohort would depend on continued cutting-cycle harvests in the overstory, and these harvests would have to be sufficiently intensive to create growing space for the establishment of new seedlings. But it would be hard to assert that the uneven-aged treatments had, after 12 years, resulted in three distinct age classes.

Suspicion that the process of converting plantations from even-aged to uneven-aged structure is inefficient has not been borne out a 12 year period in this demo. All three treatments had 12-year periodic annual increment exceeding 80 cubic feet per acre in total merchantable and sawtimber cubic volume, 450 board feet per acre Doyle, and 600 board feet per acre International ¼-inch rule.

It might appear anomalous for total merchantable cubic volume PAI to be lower than sawtimber cubic volume PAI. This is attributed to ingrowth into the sawtimber component. Murphy and Shelton (1994) reported similar results. When a tree grows past the 9.6-inch threshold, its sawtimber cubic volume goes instantly from 0 to 6.7 cubic feet, a growth of 6.7 cubic feet. Conversely, its total merchantable cubic volume goes from 10.8 to 14.1 cubic feet, a growth of 3.3 cubic feet. Thus, if ingrowth is high, as it is in this study, sawtimber cubic volume PAI can exceed that of total merchantable cubic volume PAI.

At some point in the life of these plots, volume increment of the original plantation cohort will decline. At another point, the new cohort of trees established during this 12-year period will make contributions to the stand-level PAI. Whether those two points will occur in synchrony to maintain PAI at the levels reported from this 12-year period remain to be seen, but one would suspect that the first point will be reached before the second—and thus that there will be a shortfall in PAI in the next decade or two.

Implications in the distribution of basal area in the sawtimber component are not clear. It has been suggested that the high shade from the crowns of overstory trees alone provide less competition to understory development than an equivalent amount of low shade cast by midstory trees alone (Baker and others 1996). But in this demonstration the opposite appears to be the case, because the treatments with highest percentage of RBA in sawtimber (the 80 RBA and the VCGDL) are those with the least amount of regeneration. The lack of pine regeneration in these two treatments may have resulted from the prescribed burning in the 80 RBA treatment and the generally high levels of residual basal area in both treatments. Some replicated comparisons of regeneration establishment and development beneath pure sawtimber stands versus stands of mixed sawtimber and pulpwood size classes having the same basal area would shed some light on this point.

Finally, this demonstration clearly reveals an important point about converting stands from even-aged to uneven-aged structure using single-tree selection. It is not a rapid process. After 12 years, one of these uneven-aged treatments is headed in the right direction, and the other is marginal. Another decade or two will be needed to judge whether either of these conversion treatments was successful, with new cohorts of regeneration established in sufficient density and stocking, and making acceptable diameter growth into the pulpwood and sawtimber size classes. Additional time will also be needed to determine whether there are unacceptable declines in volume increment over time. Based on this understanding, foresters who plan to undertake the conversion of an even-aged stand to uneven-aged conditions should do so only if they can commit appropriate time to the conversion; time that is more likely to be measured in decades rather than years.

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# COST EFFECTIVENESS OF NATURAL REGENERATION FOR SUSTAINING PRODUCTION CONTINUITY IN COMMERCIAL PINE PLANTATIONS

**T. R. Clason**[1]

**Abstract**—Reforestation is a key to production continuity in commercial pine plantations. Although natural and artificial regeneration methods have been used successfully for pine seedling establishment, it is seedling growth during early stage of plantation development that affects the financial potential of a pine plantation. A study was initiated to determine the effect of regeneration method on seedling growth and development. A seed tree regeneration harvest was compared to a clear cut and plant regeneration harvest. The growth of the natural stand was compared to planted plantations with initial stocking densities of 1,200 and 680 seedlings per acre. In addition, the impact of mechanical and chemical site preparation, and herbaceous weed suppression was evaluated. Merchantable volume at age 15 varied between reforestation methods, seedling stocking densities and vegetation management practices being 540, 1,715, 2,730 and 3,440 feet$^3$ per acre for natural plantation and three planted plantations, respectively. Age 15 land expectation values for the respective reforestation methods were 135, 170, 785 and 1,053 dollars per acre.

## INTRODUCTION

On cut over timber land, productivity of commercial loblolly pine (Pinus taeda L.) plantations depends on seedlings competing successfully for finite levels of soil resources. Reforestation phase of plantation development includes site preparation, regeneration (seedling establishment) and post-establishment weed suppression. Although competitive pressure exerted by an existing plant community hampers early seedling growth, seedling establishment plays a pivotal role in the reforestation process. Regenerated stands should be adequately stocked with well distributed seedlings to optimize soil exploitative potential during the first growing season.

During the first growing season, competition from hardwood brush and herbaceous weeds reduces seedling survival and decreases early diameter and height growth. Thorough site preparation suppresses this initial interference, but as the growing season progresses, encroaching vines, resurgent hardwood brush and unwanted pine seedlings begin to compete vigorously for growing space. Regeneration method, natural or artificial, can have a significant impact on mitigating competitive interference during the seedling stage of plantation development.

Natural regeneration methods have been used successfully to establish seedlings on cut over pine plantations but seedling density is usually excessive. Since, pine diameter growth loss has been detected in both dominant and intermediate crown classes of 3-year-old plantations at seedling densities that exceed 500 trees per acre (TPA) (Sprinz and others 1979), natural regeneration may not be a cost effective seedling establishment method for commercial pine plantations. A study was initiated to determine the cost effectiveness of reforestation methods on growth and development of commercial pine plantations. Growth of a seed tree regenerated plantation will be compared to clear cut and plant regenerated plantations with seedling planting densities of 1,200 and 680 seedlings per acre.

## METHODS

Data from two studies were used to compare natural and artificial regenerated pine plantation development and growth. The studies were established at the Hill Farm Research Station on the same site but in different years, 1955 and 1984. Predominant soil types are Mahan fine sandy loam (clayey, kaolinitic, thermic Typic Halpludults) and Wolfpen loamy sand (loamy, siliceous, thermic Arenic Paleudalfs) with a 25 year site index for loblolly pine of 70 feet.

### 1955 Study

The study was initiated during 1955 in a 25-year-old understock stand of old field loblolly and shortleaf pine (Pinus enchinata Mill) that had a stocking density of 167 TPA and mean DBH of 7.7 inches. The stand was subdivided into sixteen 0.5 acre plots. Twelve plots were randomly selected for a seed tree regeneration harvest that left a residual stand of approximately seven loblolly pines per plot. The four remaining plots were clear cut and prepared to plant pine seedlings. The study treatments were as follows: 1) Seed Tree Harvest and seedbed preparation by disking (STD); 2) Seed Tree Harvest and seedbed preparation by burning (STB); Seed Tree Harvest and no seedbed preparation (STCK); and Clearcut Harvest, mechanical site preparation and plant at 1,200 TPA, 6 ft x 6 ft spacing, (PMS). All logging slash was piled and burned in

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**Table 1—Age 15 stand growth attributes by reforestation treatment[a]**

| Reforestation Treatment | Stand Density | DBH | Height | Basal Area |
|---|---|---|---|---|
| | Trees/Acre | Inches | Feet | $Feet^2$/Acre |
| Seed Tree (Disced) | 1,400 | 3.5 | 33 | 94 |
| Seed Tree (Burned) | 1,421 | 3.5 | 32 | 95 |
| Seed Tree (Untreated) | 1,407 | 3.5 | 33 | 94 |
| Planted MS(1200 TPA) | 618 | 6.4 | 42 | 138 |
| Planted CS(680 TPA) | 534 | 7.0 | 45 | 142 |
| Planted CS(680 TPA HWS) | 581 | 7.4 | 47 | 175 |

[a]All trees greater than 1.0 inch dbh

August 1955 followed by seedbed and mechanical site preparation treatments. The STD treatment was broadcast disked to a depth of 4 inches with a standard lift-type tandem disk harrow, the STB treatment was burned in September and the PMS treatment was burned and then disked. Treatments were replicated four times and randomly assigned to the designated harvest plots. After 5 years, all seed trees were removed.

## 1984 Study

This study was initiated following a clear cut harvest of the 1955 Study. The study area was chemically site prepared with glyphosate applied at 4 lbs. a.i./acre and loblolly pine seedlings were planted at a 8 ft x 8 ft spacing (680 TPA). Three levels of herbaceous weed and two levels of woody brush suppression were combined in a factorial manner to establish six vegetation management regimes of varying intensity. Vegetation management regimes, in descending order of intensity, were: VMR 1) post-planting herbaceous weed suppression for 2 years and woody brush (hardwood and pine) suppression; VMR 2) post-planting herbaceous weed suppression for 1 year and woody brush suppression; VMR 3) no herbaceous weed suppression and woody brush suppression; VMR 4) post-planting herbaceous weed suppression for 2 years and no woody brush suppression; VMR 5) post-planting herbaceous weed suppression for 1 year and no woody brush suppression; and VMR 6) no herbaceous weed suppression and no woody brush suppression. Regimes were replicated six times and assigned in completely random manner to 36 0.3 acre plots. Herbaceous weed suppression treatment was applied with a backpack sprayer using sulfometuron methyl at 1.5 oz. a.i./acre in early spring of the first and second growing seasons. Woody brush suppression treatment was a backpack application of triclopyr amine at 2 lbs. ae/acre in the spring of the fourth growing season to suppress hardwood brush and woody vines and to eliminate every third row of pine seedlings. Pine stocking density in the woody brush suppression treatment plots was reduced to approximately 350 TPA. Growth data from the VMR 5 (PCSHWS) and VMR 6 (PCS) plots were used for the natural and artificial regeneration comparisons.

Growth data for both studies were collected periodically through age 15. Age 15 DBH and height were used to compute age 15 individual pine merchantable volume at a 3-inch inside bark diameter (Van Duesen and others 1981). Actual and published cost and revenue values were used to compute treatment net present value (NPV) and land expectation value (LEV). Growth data within studies were analyzed using SAS general linear model analysis of variance procedures at a 0.05 level of probability. NPV and LEV were used to compare treatment cost effectiveness among studies.

**Table 2—Age 15 product volume distribution by reforestation treatment**

| Reforestation Treatment | Product Volume Total | Pulpwood | C-N-S | Sawtimber |
|---|---|---|---|---|
| | $Feet^3$/Acre | | | |
| Seed Tree (Disced) | 540 | 540 | ----- | ----- |
| Seed Tree (Burned) | 545 | 545 | ----- | ----- |
| Seed Tree (Untreated) | 540 | 540 | ----- | ----- |
| Planted MS (1200 TPA) | 1,715 | 1,005 | 710 | ----- |
| Planted CS (680 TPA) | 2,730 | 670 | 2,030 | 40 |
| Planted CS (680 TPA HWS) | 3,440 | 690 | 2,690 | 90 |

**Table 3—DBH size class distribution by reforestation treatment**

| | Reforestation Treatment | | | | | |
|---|---|---|---|---|---|---|
| DBH Class | Seed Tree Disced | Seed Tree Burned | Seed Tree Untreated | Planted MS-1200 | Planted CS-680 | Planted CS-680-HWS |
| Inches | Trees/Acre | | | | | |
| <1.5 | 1,147 | 1,614 | 653 | 61 | ----- | ----- |
| 1.6-3.5 | 731 | 743 | 734 | 1 | ----- | ----- |
| 3.6-5.5 | 667 | 666 | 660 | 127 | ----- | ----- |
| 5.6-7.5 | 2 | 2 | 2 | 418 | 138 | 90 |
| 7.6-9.5 | ----- | ----- | ----- | 71 | 382 | 430 |
| >9.6 | ----- | ----- | ----- | ----- | 14 | 61 |
| Total | 2,547 | 3,025 | 2,049 | 678 | 534 | 581 |

## RESULTS

### 1955 Study Growth

Stand growth differences were detected among reforestation treatments. Although seed tree seedbed preparation did not affect stand productivity, mean seed tree treatment and the PMS treatment growth attributes were significantly different (table 1) . Mean seed tree treatment merchantable tree density exceeded the PMS treatment density by 800 TPA (table 1). However, seed tree basal area and merchantable volume were 47 and 60 percent less than the PMS treatment (tables 1 and 2). Pulpwood and chip-n-saw volume differed between seed tree and PMS treatments with seed tree respective volumes being 465 and 710 feet$^3$ per acre less than the PMS treatment (table 2). Tree diameter distribution varied between seed tree and PMS treatments. Fifty two percent of the seed tree merchantable stems fell within the 2 to 4 inch DBH class, while 91 percent of the PMS stems were greater than 4 inches (table 3).

### 1984 Study Growth

Mean tree DBH and height, and stand basal area and merchantable volume differed significantly between treatments (tables 1 and 2). No stand density differences were detected at age 15, but tree survival rates averaged 78 and 85 percent for the PCS and PCSHWS treatments. Although the PCS treatment had 47 fewer trees, mean tree DBH and height were 0.4 inches and 2 feet less than the PCSHWS treatment. Basal area and merchantable volume treatment differences were 33 feet$^2$ per acre and 710 feet$^3$ per acre. Treatment volume differential was reflected in product volume distribution, PCSHWS chip-n-saw and sawtimber volumes exceeded the PCS volumes by 690 feet$^3$ per acre (table 2). Tree DBH distribution varied between treatments with PCSHWS treatment having 95 more trees in the 8 inch and larger DBH class, and 66 percent were 10 inches or larger (table 3).

### Financial Comparisons

Since seed tree treatment growth was similar for all seedbed preparation treatments, two seed tree options were compared by pooling growth data, assuming no seedbed preparation cost and leaving or removing seed tree stand for the 15 year comparison period. Therefore, financial comparisons treatments were seed tree with no seed tree removal, seed tree with seed tree removal at age 5, PMS, PCS and PCSHWS. Cost values were determined by actual and published costs (Dubois and others 1999). Revenue values were based on the mean 10-year Louisiana stumpage prices for pulpwood, chip-n-saw and sawtimber between 1991 and 2000. Seed tree treatment costs included the value of the residual seed trees, while planted treatment costs included site preparation, seedling purchase and planting, and herbaceous weed suppression for the PCSHWS treatment. All costs and revenues were discounted at a 8 percent interest rate.

**Table 4—Age 15 financial comparisons by reforestation treatment**

| Reforestation Treatment | Costs | Revenues | NPV | LEV |
|---|---|---|---|---|
| | Dollars/Acre | | | |
| Seed Tree (No Harvest) | 440 | 48 | (-392) | (-244) |
| Seed Tree (Harvest) | 440 | 532 | 92 | 135 |
| Planted MS(1200 TPA) | 194 | 311 | 117 | 170 |
| Planted CS(680 TPA) | 164 | 702 | 538 | 785 |
| Planted CS(680 TPA HWS) | 200 | 921 | 721 | 1,053 |

Regeneration method did influence the financial potential of commercial pine plantations. At an 8 percent discount rate, failure to capture seed tree value resulted in a negative NPV and LEV at age 15 (table 4). Although seed tree removal at age 5 produced positive NPV and LEV values, these values were less than any of the planted treatments. Initial planting density and site preparation method impacted the financial potential of the planted treatments, PMS treatment NPV and LEV were $422 and $615 per acre less than PCS treatment (table 4). Although there was no cost differential between mechanical and chemical site preparation, chemical site preparation provided better vegetation suppression during early seedling growth and development. First year herbaceous weed suppression (PCSHWS) improved the financial potential of chemically site prepared planted plantations, increasing NPV and LEV by $187 and $188 per acre.

## CONCLUSIONS

Reforestation practices had a significant impact on the financial potential of commercial pine plantations:

1. Seed tree regeneration method was the least cost effective reforestation method. Excessively stocked plantations were susceptible to intraspecific competi tion which reduced growth productivity.
2. In planted plantations, chemical site preparation was more cost-effective than a low intensity mechanical treatment.
3. Wider spaced planting density and first year weed suppression improved reforestation cost effectiveness on the planted plantations

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# IMPACT OF SUSTAINABLE FOREST MANAGEMENT ON HARVEST, GROWTH, AND REGENERATION OF SOUTHERN PINE IN THE PIEDMONT AFTER 5 YEARS OF MONITORING

**Alexander Clark III and James W. McMinn**[1]

**Abstract**—This paper describes a study established to monitor the implications of ecosystem management choices on natural loblolly and shortleaf pine stands on the Oconee National Forests in the Piedmont of Georgia. The impact of partial harvests, group selection cuts, seed tree cuts and no human disturbance on growth, mortality, species composition, and regeneration were monitored from 1994-95 to 1999. In mature stands with no human disturbance growth average 4.7 percent per acre per year and mortality averaged 2.9 percent per acre per year. In stands with partial cuts growth averaged 6.1 percent and mortality averaged 2.4 percent per acre per year. Sweetgum and red maple were the predominant regeneration seedling species in stands with partial cuts and group selection cuts. Loblolly pine was the predominant seedling species in the seed tree cuts. Seed tree cuts appear to be the most successful forest management method for regenerating loblolly pine stands in the Piedmont.

## INTRODUCTION

Piedmont National Forest lands have been managed under the multiple-use concept since the 1960's. Under this concept, objectives were to improve the health, quality and volume of pine stands as well as a variety of other benefits. Older pine stands were clear-cut and planted back to pine or harvested using seed tree cuts to establish pine regeneration. Younger stands were thinned to stimulate pine sawtimber growth.

In the early 1990's an ecosystem approach to managing National Forests was introduced to improve the balance among forest values, conserve biodiversity, and achieve sustainable, healthy conditions while retaining the spiritual, historic and esthetic qualities of the land. Under ecosystem management pine and pine/hardwood stands on National Forests in the Piedmont are being converted from evenaged monocultures to unevenaged or two-aged pine and mixed species stands.

This paper reports on a study established to monitor the implications of ecosystem management practices on loblolly (*Pinus teada* L.) and shortleaf (*P. Echinata* Mill) pine natural stands on the Oconee NF in the Piedmont of Georgia. The impact of partial cuts, group selections cuts, seed tree cuts and no human disturbance on harvest volumes; growth; mortality; and seedling density, species composition, richness, diversity, and evenness are reported.

## METHODS

Permanent monitoring plots were established in loblolly/shortleaf pine stands on the Oconee NF in the Piedmont to monitor the reponses of these stands to a range of sustainable ecosystem management practices. The monitoring plots were established in 1994-95 and re-measured in 1999. The management practices monitored included: (1) partial cuts, (2) group selection cuts, (3) seed tree cuts and (4) no active management areas. Included in the partial cuts is single-tree selection, salvage cuts, stand improvement cuts and shelterwood cuts. No active management areas are stands in which no human disturbance occurred between stand inventories in 1994-95 and 1999. The group selection openings were 150 to 200 feet in diameter. Each monitoring plot is a cluster group (CG) consisting of three 1/5-acre circular plots and that were randomly located within each stand selected for monitoring. Cluster groups were established in stands representative of four 20-year age classes (20,40,60, and 80 years) (table 1).

On each 1/5-acre plot all trees m 5.0 inches diameter at breast height (d.b.h.) was located by azimuth and distance from plot center. Species, d.b.h., total height, merchantable height, and tree grade were recorded for each live and

**Table 1—Number of Natural Stands Monitored by Management Practice and Age Class**

| Age Class (Yrs) | No Activity | Partial Cut | Group Selection | Seed Tree |
|---|---|---|---|---|
| | ———— | ——No.—— | ———— | ———- |
| 20 | 2 | 1 | | |
| 40 | 2 | | | |
| 60 | 4 | 4 | 2 | 1 |
| 80 | 2 | 2 | | 4 |

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**Table 2—Average Proportion of Basal Area by Species Group for Trees  = 5.0 inches DBH Measured in 1994-95 and Remeasured in 1999 by Management Practice**

| Stand Age | 1994-95 Species Group: Pine | Soft Hwds | Oaks | Other Hard Hwds | 1999 Species Group: Pine | Soft Hwds | Oaks | Other Hard Hwds |
|---|---|---|---|---|---|---|---|---|
| Yrs | | | | | % | | | |
| | | | | No Active Management | | | | |
| 15 | 87 | 3 | 10 | 0 | 91 | 1 | 8 | 0 |
| 43 | 88 | 12 | 0 | 0 | 86 | 13 | 1 | 0 |
| 62 | 75 | 23 | 1 | 1 | 79 | 20 | 1 | 0 |
| 72 | 80 | 13 | 3 | 4 | 80 | 13 | 2 | 5 |
| | | | | Partial Cuts | | | | |
| 22 | 97 | 2 | 1 | 0 | 96 | 2 | 2 | 0 |
| 57 | 92 | 6 | 2 | 0 | 94 | 4 | 2 | 0 |
| 80 | 83 | 8 | 5 | 4 | 84 | 6 | 6 | 4 |
| | | | | Group Selection Cuts | | | | |
| 60 | 83 | 16 | 0 | 0 | 4 | 91 | 0 | 5 |
| | | | | Seed Tree cut – No Active cut | | | | |
| 60 | 91 | 9 | 0 | 0 | 96 | 4 | 0 | 0 |
| 75 | 83 | 6 | 10 | 1 | 85 | 2 | 12 | 1 |
| | | | | Seed Tree Cut-Active Cut | | | | |
| 70 | 83 | 14 | 1 | 2 | 82 | 14 | 0 | 4 |

dead tree. Five 1/300-acre micro-plots were located 30 feet from plot center at 72° intervals within each 1/5-acre plot to tally seedlings and saplings. Seedlings (trees up to 1.0-inch d.b.h.) were tallied by species count. Saplings (trees 1.0 to 4.9 inches d.b.h.) were tallied by species, d.b.h. and total height. Softwoods 5.0 to 8.9 inches d.b.h. and hardwoods 5.0 to 10.9 inch d.b.h. were classified as pole timber. Softwoods m 9.0- and hardwoods m 11.0 inches d.b.h. were classified as sawtimber if they contained one or more 16-foot sawlog. Pine sawtimber trees were classified using a tree classification system for mature pine developed by Clark and McAlister (1998) and hardwood sawtimber trees were classified using USDA Forest Service hardwood tree grades (Hanks, 1976).

Stem green weight of wood and bark to a 4 inch dob top was estimated for trees m 5.0 inches dbh based on DBH and total height using equations developed for natural pine in the Piedmont (Clark and others 1990). Stem weight of soft hardwoods, oaks and other hard hardwoods were estimated using equations developed for hardwoods in the southeast (Clark and others 1986). The equations were applied to the dbh and total height measurements recorded for each live tree in 1994-95 and live and dead trees

**Table 3—Average Stem Green Biomass/Acre in 1994-95, Biomass in 1999, Harvest, Mortality and Growth for Stands Monitored**

| Avg Age Yrs | 1994-95 Inventory TNS/A | Harvest TNS/A | 1999 Inventory TNS/A | Mortality % | Annual Growth[1/] % |
|---|---|---|---|---|---|
| | | | No Active Management | | |
| 15 | 16 | 0 | 39 | 6.3 | 36.0 |
| 43 | 89 | 0 | 109 | 3.7 | 5.8 |
| 62 | 69 | 0 | 80 | 3.8 | 5.1 |
| 72 | 156 | 0 | 178 | 1.3 | 3.9 |
| | | | Partial Cuts | | |
| 22 | 67 | 29 | 61 | 2.4 | 12.2 |
| 57 | 103 | 24 | 89 | 2.7 | 2.8 |
| 80 | 112 | 33 | 85 | 4.8 | 3.2 |
| | | | Group Selection Cuts | | |
| 60 | 108 | 105 | 3 | 0.4 | 11.0 |
| | | | Seed Tree Cut – No Activity | | |
| 60 | 31 | 0 | 37 | 0.3 | 3.6 |
| 75 | 42 | 0 | 50 | 0.6 | 4.8 |
| | | | Seed Tree Cut – Active Cut | | |
| 70 | 125 | 79 | 49 | 4.2 | 4.0 |

1999. Estimated tree weights were expanded to tons per acre. Trees tallied as dead standing and down dead in 1999 but were live in 1994-95 were classified as mortality. Trees cut and hauled were classified as harvest. Average annual mortality was calculated using the following equation:

Mortality = ((dead / intinv) / yrsgrw) * 100
Where: Mortality = average annual mortality in percent
dead = stem weight of dead trees (tons)
intinv = stem weight of live trees in 1994-95 (tons)
yrsgrw = number of years of growth from 1994-95 to 1999

Average annual growth was estimated using the following equation:

Growth = ((99inv-(intinv-dead-harv ) / intinv)/ yrsgrw)* 100
Where:
Growth = average annual growth in percent
Harv = stem weight of trees cut and hauled (tons)

Species diversity and evenness were calculated using Shannon's indices of diversity and evenness based on stem counts (Magurran, 1988).

## RESULTS

### NO ACTIVE MANAGEMENT

The stands that received no active management contained 75 to 88 percent of their basal area (BA) in pine, 3 to 23 percent in soft hardwoods and the remainder in oaks and other hard hardwoods based on the 1994 inventory (table 2). The remeasurement data shows the BA of these stands changed only slightly from 1994 to 1999. The average total green weight of stems per acre ranged from 16 tons on the 15-year stands to 156 tons on the 72-year stand in 1994-95 (table 3). The stand stem biomass/acre increased on all stands with no active management. Average annual growth among sawtimber stands ranged from 5.8 percent for the 43-year stand to 3.9 percent for the 72-year stand. Average mortality ranged from 3.8 percent for the 62-year stand to only 1.3 percent for the 72-year stand. The average mortality of 15-year stands was 6.3 percent per acre per year. However, these young stands were growing at 36 percent per acre per year because of a 40 percent in-growth from saplings to pole timber from 1994 to 1999 and an average increase in quadratic mean DBH from 6.7 to 7.5 inches (table 4).

Average stems per acre for seedlings decreased in all stands that received no active management from 1994 to 1999 by an average of 58 percent and species richness decreased slightly. This decrease in seedling stems per acre was probably a result of the drought conditions in 1998 and 1999 in the Piedmont. On average species diversity and evenness increased slightly (table 5). The most predominant seedling species in 1994-95 were red maple and dogwood, but in 1999 sweetgum and red maple were the most predominant species in the stands receiving no active management (table 6).

### PARTIAL CUTS

Harvesting had little effect on the proportion of BA that was in pine, soft hardwood, oaks or hard hardwood in the partial cut stands (table 2). Before harvest the stands averaged 83 to 97 percent pine and following harvest the stands averaged 84 to 96 percent pine. Number of trees per acre (TPA) before thinning ranged from 390 in the 22-year stand to 103 TPA in the 57-year stand (table 4). After the thinning TPA ranged from 83 in the 22-year stand to 67 in the 57-year stand. The average stem weight per acre before thinning ranged from 67 tons per acre in the 22-year stand to 112 tons per acre in the 80-year stand in 1994-95 (table 3). In the thinning operation 43 percent of the stem biomass in the

**Table 4—Average Stand Basal Area/Acre, Trees per Acre (TPA) and Quadratic Mean DBH (QDBH) for Tree = 5.0 Inches DBH Measured in 1994-95 and Remeasured in 1999 by Management Practice**

| Stand Age (Yrs) | 1994-95 Basal Area ($Ft^2$) | 1994-95 TPA (No.) | 1994-95 QDBH Area (In.) | 1999 Basal ($Ft^2$) | 1999 TPA (No.) | 1999 QDBH (In.) |
|---|---|---|---|---|---|---|
| No Active Management | | | | | | |
| 15 | 40 | 165 | 6.7 | 71 | 231 | 7.5 |
| 43 | 77 | 78 | 13.5 | 87 | 80 | 14.1 |
| 62 | 68 | 101 | 11.1 | 72 | 100 | 11.5 |
| 72 | 126 | 167 | 11.8 | 132 | 169 | 12.0 |
| Partial Cuts | | | | | | |
| 22 | 117 | 390 | 7.4 | 83 | 193 | 8.9 |
| 57 | 86 | 103 | 12.4 | 67 | 68 | 13.4 |
| 80 | 105 | 147 | 11.4 | 73 | 89 | 12.3 |
| Group Selection Cuts | | | | | | |
| 60 | 98 | 115 | 12.5 | 5 | 15 | 7.8 |
| Seed Tree Cut – No Activity | | | | | | |
| 60 | 28 | 23 | 14.9 | 30 | 22 | 15.8 |
| 75 | 33 | 21 | 16.9 | 37 | 23 | 17.2 |
| Seed Tree Cut – Active Cut | | | | | | |
| 70 | 108 | 117 | 13.0 | 37 | 12 | 23.8 |

**Table 5—Average Stem/Acre, Species Richness, Diversity and Evenness for Seedlings for Stands Measured in 1994-95 and Remeasured in 1999 by Management Practice**

| Stand Age (Yrs) | 1994-95 Stems/Acre (No.) | Richness | Diversity | Evenness | 1999 Stems/Acre (No.) | Richness | Diversity | Evenness |
|---|---|---|---|---|---|---|---|---|
| | | | | No Active Management | | | | |
| 15 | 7,840 | 21 | 2.2 | 0.7 | 3,900 | 16 | 2.1 | 0.8 |
| 43 | 10,040 | 17 | 1.7 | 0.6 | 3,980 | 13 | 1.9 | 0.8 |
| 62 | 9,340 | 19 | 2.1 | 0.7 | 6,240 | 18 | 2.3 | 0.8 |
| 72 | 45,860 | 23 | 1.4 | 0.5 | 16,520 | 21 | 1.5 | 0.5 |
| | | | | Partial Cuts | | | | |
| 22 | 1,820 | 15 | 2.2 | 0.8 | 4,360 | 18 | 1.9 | 0.7 |
| 57 | 11,300 | 20 | 2.0 | 0.7 | 9,451 | 17 | 2.0 | 0.7 |
| 80 | 12,140 | 21 | 1.8 | 0.6 | 10,480 | 20 | 2.0 | 0.7 |
| | | | | Group Selection Cuts | | | | |
| 60 | | | | | | | | |
| | | | | Seed Tree cut – No Active cut | | | | |
| 60 | 5,740 | 23 | 1.9 | 0.6 | 8,120 | 17 | 1.9 | 0.7 |
| 75 | 12,340 | 17 | 1.8 | 0.6 | 9,140 | 19 | 1.9 | 0.7 |
| | | | | Seed Tree Cut-Active Cut | | | | |
| 70 | 16,540 | 25 | 1.9 | 0.6 | 8,840 | 16 | 2.7 | 0.7 |

pole and sawtimber class was harvested in the 22-year stand, 23 percent in the 57-year stand and 29 percent harvested in the 80-year stand. Average mortality ranged from 2.4 percent in the 22-year stand to 4.8 percent in the 80-year stand. Average annual growth ranged from 12.2 percent in the 22-year stand to 2.8 percent in the 57-year stand. Seedling stems per acre increased significantly after the thinning in the 22-year stand but decreased only slightly in the 57 and 80-year stands (table 5). Loblolly pine, red maple and sweetgum were the predominant seedling species in the partial cut stands before harvest in 1994-95. Following harvest in 1999 sweetgum was the predominant seedling species in all partial cut stands.

## GROUP SELECTION CUTS

The group selection openings contained 83 percent of their BA in pine and 16 percent in soft hardwoods before the openings were cut (table 2). After the openings were harvested they contained only 4 percent of their BA in pine and 91 percent in soft hardwoods. Harvesting in the group openings removed 105 tons per acre or 97 percent of the pole and sawlog biomass in the openings (table 3). On average the openings contained 98 TPA before harvest and 15 TPA after harvest (table 4). The trees remaining in the openings were growing at an annual average rate of 11 percent and averaged 7.8 inches DBH in 1999. Before harvest the predominant seedling species was dogwood

**Table 6—Proportion of Seedling Stems per Acre (%) by Species for Stands Measured in 1994-95 and Remeasured in 1999 by Management Practice**

| Stand Age (Yrs) | -------------------------1994-95------------------------- Species | | | ------------------------1999---------------------------- Species | | |
|---|---|---|---|---|---|---|
| | | | | No Active Management | | |
| 15 | R. Maple (20) | Sweetgum(15) | Water Oak(11) | Sweetgum(16) | Dogwood(14) | R. Maple(12) |
| 43 | Dogwood(27) | Lob. Pine(26) | Sweetgum(13) | Sweetgum(23) | Lob. Pine(18) | Dogwood(16) |
| 62 | Dogwood(19) | Lob. Pine(19) | Sweetgum(12) | R. Maple(13) | Lob. Pine(12) | Dogwood(11) |
| 72 | R. Maple(6) | Dogwood(17) | Elm(3) | R. Maple(65) | Dogwood(11) | Elm(18) |
| | | | | Partial Cuts | | |
| 22 | Sweetgum(37 | S. Red Oak(9) | Dogwood(9) | Sweetgum(34) | Lob. Pine(32) | B. Cherry(5) |
| 57 | Lob. Pine(35) | Sweetgum(15) | R. Maple(7) | Sweetgum(27) | Lob. Pine(21) | Elm(6) |
| 80 | R. Maple(31) | Sweetgum(17) | Lob. Pine(13) | Sweetgum(26) | R. Maple(12) | Lob. Pine(4) |
| | | | | Group Selection Cuts | | |
| 60 | Dogwood(24) | Lob. Pine(21) | Sweetgum(20) | Sweetgum(40) | Water Oak(18) | Dogwood(16) |
| | | | | Seed Tree Cut – No Active Cut | | |
| 60 | Lob. Pine(45) | Sweetgum(24) | Water Oak(4) | Hawthorn(31) | Lob. Pine(25) | Sweetgum(15) |
| 75 | Lob. Pine(50) | R. Maple(11) | Sweetgum(7) | Lob. Pine(36) | R. Maple(7) | Sweetgum(7) |
| | | | | Seed Tree Cut – Active Cut | | |
| 70 | Lob. Pine(37) | R. Maple(17) | Dogwood(15) | Lob. Pine(37) | Sweetgum(20) | Elm(9) |

followed by loblolly pine. Four years after harvesting the openings sweetgum followed by water oak was the predominant seedling species.

## SEED TREE CUT- NO ACTIVE CUT

The proportion of BA per acre in pine increased slightly (2 to 5 percent) and proportion in soft hardwoods decreased slightly (4 to 5 percent) from 1994-95 to 1999 on the stands that were seed tree stands prior to 1994 (table 2). The seed tree stands with on active cut averaged 21 to 23 TPA m 5.0 inches DBH and contained 30 to 37 tons of stem biomass per acre in 1999. The stands were growing at an annual rate of 3.6 to 4.8 percent and had an average mortality of 0.3 to 0.6 percent per year (table 3). Average quadratic mean DBH of the seed trees was 15.8 in the 60-year stand and 17.2 in the 75-year stand (table 4). Stems per acre in seedlings increased from 1994-95 to 1999 on the 60-year stand by 41 percent but decreased on the 75 year stand by 47 percent. In 1994-95 the predominant regeneration seedling species was loblolly pine in the seed tree stands with no active cut. Five years after the initial measurements hawthorn was the predominant seedling species in the 60-year stand but loblolly pine was still the predominant species in the 75-year stands. However, over time the loblolly pine seedlings in the 60-year stand should gain dominance over the hawthorn.

## SEED TREE CUT – ACTIVE CUT

Prior to harvest the stand that received the seed tree cut contained 108 TPA m 5.0 inches DBH and 83 percent of its BA per acre was in pine, and 14 percent was in soft hardwoods (table 2). Following the seed tree cut the stand contained only 12 TPA but the proportion of BA per acre in pine and hardwoods was about the same as that prior to harvest. Harvesting removed 79 tons per acre or 63 percent of the stem biomass in the stand (table 3). Following the harvest the remaining seed trees were growing at an average rate of 4.0 percent per year and had an average mortality of 4.2 percent per year. The number of seedling per acre decreased from over 16, 540 per acre prior to the harvest to 8,840 in 1999 or by 47 percent. This decrease was probably a direct result the 1998 and 1999 droughts. In 1994-95 loblolly pine was the predominant seedling species and in 1999, four year after the seed tree cut, loblolly pine was still the predominant species.

## SUMMARY

The impact of partial harvests, group selections cuts, seed tree cuts and no human disturbance on growth, mortality, species composition and regeneration were monitored for natural pine stands on the Oconee National Forest in the Piedmont of Georgia from 1994-95 to 1999. The stands monitored contained 75 to 92 percent of their basal area in pine, 3-23 percent in soft hardwoods and 0 to 10 percent in hard hardwoods. The stands monitored ranged in age from 15 to 80 years old. In stands over 20 years old, with no human disturbance, the average annual growth was 4.7 percent and annual mortality averaged 2.9 percent. In stands with partial cuts growth averaged 6.1 percent and mortality averaged 2.4 percent. In stands with no human disturbance sweetgum and red maple were the predominant seedling species. In stands with partial cuts and group selection cuts sweetgum was the most predominant regeneration species. Loblolly pine was the predominant seedling species in the seed tree cuts. Seed tree cuts appear to be the most successful method for regenerating loblolly pine stands in the Piedmont.

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# REGENERATION HISTORY OF THREE TABLE MOUNTAIN PINE/PITCH PINE STANDS IN NORTHERN GEORGIA

**Patrick Brose, Frank Tainter, and Thomas Waldrop**[1]

**Abstract—**A dendrochronology study was conducted on three ridgetop pine communities in northern Georgia to document the current composition and structure, ascertain when the different species became established, and compare their establishment dates with the occurrence of disturbance or drought. Most oaks and pines in these stands date to the early 1900's and became established after major disturbances by disease, logging, and wildfire. The mountain laurel and mixed mesophytic hardwoods became established after the chestnut blight and institution of wildfire control policies. Drought and precipitation appear to have played little role in the establishment of either pine species. Given the ubiquitous presence of hardwoods and the dominance of mountain laurel in the understory, a regime of no disturbance or a single stand-replacing disturbance may not successfully regenerate either pine species in these stands. Numerous low- to moderate-intensity disturbances may be necessary to reduce the hardwood and laurel components and prepare seedbeds for pitch and Table Mountain pine.

## INTRODUCTION

The Southern Appalachian Mountains are renown for their diversity of forest types, one of which is the Table Mountain pine (*Pinus pungens*) / pitch pine (*P. rigida*) community. This rare forest type is found throughout the region on xeric mid-elevational south- and west-facing ridges (Zobell 1969). These species are thought to be fire dependant because of cone serotiny in Table Mountain pine, extreme shade intolerance and exposed seedbed requirements by both species, and a successional shift to hardwoods in the absence of fire (Williams and Johnson 1992). The fire regime for successful regeneration of pitch and Table Mountain pine is thought to be infrequent high-intensity fire, the type of fire that now rarely occurs due to the successful fire control policies of the past 70-80 years (Welch and others 2000).

Recent research has not conclusively shown that high-intensity prescribed fires are absolutely necessary, or even beneficial, in perpetuating Table Mountain pine / pitch pine communities. Waldrop and Brose (1999) analyzed the effects of varying fire intensity levels on successful establishment of Table Mountain pine regeneration. They found the fewest new stems and lowest stocking on sites that had experienced a high-intensity crown fire while the most new stems and highest stocking occurred on sites treated with a moderate-intensity surface fire. However, other low- and moderate-intensity prescribed fires have not resulted in successful establishment of new pine regeneration (Elliot and others 1999, Welch and others 2000).
If fire was an integral part of the perpetuation of Table Mountain pine / pitch pine stands but high-intensity, stand-replacing prescribed fires are not adequately regenerating them, then what was the disturbance regime under which these stands originated and developed? Dendrochronology can be used to help answer that question. The application of this approach to stand dynamics integrates radial growth analysis, species establishment dates, and historic weather records to reconstruct how a stand was initiated and grew into its present state. Dendrochronology is receiving increased usage to reconstruct past disturbance regimes and understand successional dynamics (Mikan and others 1994; Abrams and Orwig 1995) but has only once been used to examine the origin and development of Table Mountain pine communities (Sutherland and others 1995).

In this study, we use dendrochronology to determine when three Table Mountain pine / pitch pine stands originated, how they developed to their present state, and the influence of disturbance and drought on that development.

## METHODS

The study was conducted in three stands (Big Ridge, Lower Tallulah, and Upper Tallulah) containing a substantial pitch pine and Table Mountain pine component located in the Chattahoochee National Forest of northern Georgia. The stands were approximately 20-30 ac each, situated on the tops and upper side slopes of two south-facing ridges near Rabun Bald. Elevation for two of the stands was from 3200–3600 ft while the third was at 2800–3000 ft. Soil in all three stands was of the Ashe series which is

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**Table 1—Basal area, density, stocking, and relative importance values of tree species found in three Table Mountain pine / pitch pine stands in northern Georgia**

| Stand | Species[a] | Stems/ac | Stocking | BA/ac | Imp. Value |
|---|---|---|---|---|---|
| Upper | QUPR | 112 | 100 | 55.0 | 25.75 |
| Tallulah | PIPU | 64 | 77 | 60.3 | 20.92 |
| | YSY | 82 | 70 | 21.2 | 15.18 |
| | QUCO | 39 | 73 | 19.2 | 11.26 |
| | CADE | 53 | 67 | 0.8 | 8.87 |
| | ACRU | 22 | 67 | 5.1 | 6.87 |
| | OXAR | 15 | 33 | 8.7 | 4.90 |
| | QUAL | 9 | 20 | 11.2 | 3.95 |
| | AMAR | 11 | 36 | 2.1 | 3.58 |
| | SAAL | 5 | 17 | 1.3 | 1.65 |
| | ROPS | 2 | 7 | 1.3 | 1.01 |
| | CAGL | 2 | 7 | 0.7 | 0.53 |
| Big Ridge | | | | | |
| | QUPR | 120 | 100 | 53.4 | 21.52 |
| | PIPU | 136 | 100 | 36.0 | 19.44 |
| | QUCO | 51 | 86 | 18.9 | 10.46 |
| | NYSY | 56 | 71 | 9.2 | 8.37 |
| | QUAL | 37 | 57 | 14.6 | 7.50 |
| | ACRU | 33 | 64 | 6.7 | 6.17 |
| | PIRI | 9 | 43 | 20.7 | 6.13 |
| | CADE | 40 | 71 | 1.1 | 5.96 |
| | OXAR | 13 | 43 | 12.0 | 4.88 |
| | AMAR | 20 | 50 | 3.5 | 4.13 |
| | CAGL | 9 | 29 | 3.5 | 2.45 |
| | SAAL | 4 | 7 | 6.9 | 1.81 |
| | PIST | 3 | 14 | 2.0 | 1.17 |
| LowerTallulah | | | | | |
| | PIPU | 50 | 100 | 37.8 | 15.96 |
| | QUCO | 72 | 93 | 30.8 | 15.61 |
| | NYSY | 116 | 100 | 11.8 | 14.92 |
| | QUPR | 82 | 100 | 21.5 | 14.86 |
| | ACRU | 70 | 100 | 7.0 | 10.83 |
| | PIRI | 21 | 36 | 30.1 | 9.44 |
| | CADE | 31 | 50 | 0.9 | 4.60 |
| | PIST | 15 | 21 | 5.2 | 3.08 |
| | COFL | 16 | 29 | 2.7 | 3.00 |
| | CAGL | 13 | 29 | 1.4 | 2.53 |
| | SAAL | 9 | 29 | 2.2 | 2.42 |
| | ROPS | 3 | 21 | 3.6 | 1.60 |
| | OXAR | 2 | 14 | 3.8 | 1.22 |

a - Species codes are the first two letters of the genus and species names, e.g., QUPR = Quercus prinus.

a moderately deep, somewhat excessively well drained soil formed in place by weathering of biotite gneiss and schist (Carson and Green 1981).

In each stand, 12 0.05-ac rectangular plots were selected from previously established plots (Waldrop and Brose 1999) based on presence of Table Mountain pine and location to ensure uniform coverage of the entire stand. In each plot, all trees were identified to species, categorized as dominant, co-dominant, intermediate, or suppressed and measured for dbh. All shrubs were identified to species in two 0.0125-ac rectangular subplots and their heights measured to the nearest 0.5 ft. Percent shrub cover was determined by measuring each shrub canopy twice to the nearest half-foot, first at its widest point then at a right angle to that measurement, averaging the two results, and calculating the area as a proportion of the subplot.

Importance Values (IV) for each species were calculated for each stand from the basal area, density, stocking data.

In each plot, one increment core was extracted from each of three or four dominant/codominant trees and each of three or four intermediate trees. Cores were taken from the uphill side of each tree at a height of 1-ft above the ground in hope of intersecting hidden fire scars. Also in each plot, six to eight cross-sectional discs were cut from shrubs and suppressed trees at the ground line.

Cores were air-dried for several weeks, mounted, and sanded with sandpaper of increasing fineness (120, 220 320, and 400 grit) to expose the annual rings. Cross-sections were similarly dried and sanded. The establishment date for each core and cross-section was determined by absolute aging to the pith under a 40x dissecting microscope. A pith estimator for each species was prepared from cores that intersected the pith and this estimator was then used to age cores that did not intersect the pith.

All pitch and Table Mountain pine cores were visually examined for damage, twisting, or gaps and those exhibiting discongruities were discarded. Annual ring width of the remaining cores was measured to 0.01 mm commencing at the pith and proceeding outward to the bark using a Bannister increment measuring device (J.C. Henson, Laguna Niguel, CA). The raw ring width data were detrended and converted to mean growth indices for each site using ARSTAN (Laboratory of Tree Ring Research, Tucson, AZ).

For ease of reporting the establishment dates, hardwood species of similar silvics were grouped together, i.e., mesic hardwoods included flowering dogwood (*Cornus florida*), red maple (*Acer rubrum*), sourwood (*Oxydendron arborum*), and serviceberry (*Almalanchier alnifolia*) while xeric hardwoods contained American chestnut (*Castanea dentata*), blackgum (*Nyssa sylvatica*), chestnut oak (*Quercus prinus*), pignut hickory (*Carya glabra*), sassafras (*Sassafras albidum*), and scarlet oak (*Q. coccinea*). Mountain laurel (*Kalmia latifolia*), pitch pine, and Table Mountain pine are presented as individual species.

Monthly Palmer Drought indices for Rabun County, GA from 1895 to 2000 were obtained from the National Oceanographic and Atmospheric Administration's website.

## RESULTS

All three stands were quite similar in their species composition, structure, density, stocking, total basal area, and relative importance values ( table 1). In the overstory, Table Mountain pine and chestnut oak were the dominant conifer and xeric hardwood species, respectively. Pitch pine and scarlet oak were also present in the overstory, although they were not as abundant or widespread as Table Mountain pine and chestnut oak. In the midstory, xeric and mesic hardwoods dominated, especially scarlet oak, blackgum, and red maple while the two pine species were poorly represented. The understory consisted almost exclusively of dense mountain laurel. This shrub layer averaged 8.5 ft tall and was nearly ubiquitous in Big Ridge and Upper Tallulah, cover averaged 77 percent and 89 percent respectively, while in Lower Tallulah, mountain laurel was not as widespread (36 percent coverage). In all three stands, American chestnut stump sprouts were fairly abundant (30-50 stems/acre) and widespread (50-71 percent stocking).

A total of 209 cores and 263 cross-sections was collected from the three stands. Nearly all cores were sound as little difficulty was encountered in extracting them from the trees. Distribution of cores by species group was 47 percent Table Mountain pine, 27 percent xeric hardwood, 17 percent PP, and 7 percent mesic hardwood. Cross-section distribution was 51 percent mountain laurel, 32 percent xeric hardwood, 15 percent mesic hardwood, and 2 percent Table Mountain pine. Thirty of the cross-sections contained exposed or hidden scars. Of those, 19 were from Big Ridge and the scar dated to 1996 (a low-intensity wildfire). The remainder were dated and grouped as 1971 - Lower Tallulah, 4 scars; 1963 - Upper Tallulah, 4 scars; and 1946 - Lower Tallulah, 3 scars. Also at Big Ridge, several large, hollow chestnut oaks and cat-faced pines were found.

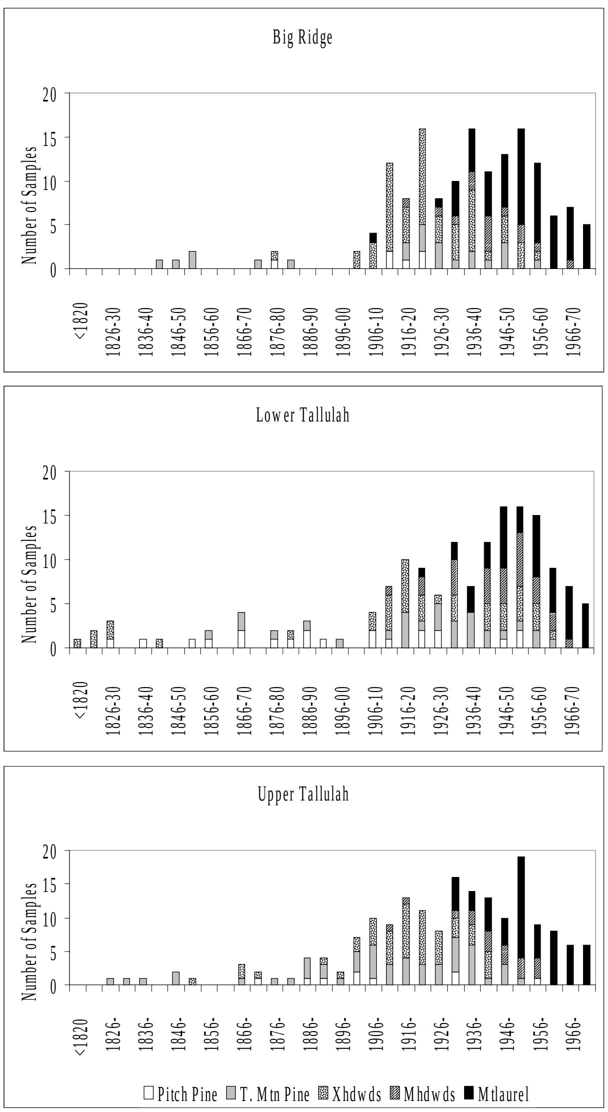


Figure 1—Species establishment dates for three Table Mountain pine stands in northern Georgia.

Species establishment dates and trends were quite similar among the three sites (figure 1). Generally, the oldest trees dated to the early- to mid-1800's and were Table Mountain pine at Big Ridge and Upper Tallulah or chestnut oak and pitch pine at Lower Tallulah. All three species became established in modest episodic amounts during the $19^{th}$ century. Commencing in the early 1900's and continuing through the 1950's, successful regeneration of Table Mountain pine and the xeric hardwoods (primarily oak) increased relative to the 1800's and were continual in all three stands while pitch pine establishment remained modest and episodic. Pine and xeric hardwood establishment peaked twice in all three stands, first between 1915 and 1925 and again in the early 1930's. Thereafter, establishment of these species declined steadily, eventually ceasing in the late 1950's. Mesic hardwoods, primarily red maple, initially showed up in all three stands beginning in the 1910's and 1920's and were continually established in small to moderate numbers through the 1960's with the 1940's being the decade of most mesic hardwood establishment. Like the oaks, mesic hardwoods have not successfully regenerated in these stands for several decades. Mountain laurel shows up in the stands commencing in the late 1920's. Over the next 50 years it was continually established in large numbers at Big Ridge and Upper Tallulah and to a lesser extent at Lower Tallulah.

The growth index chronologies for both pine species and chestnut and scarlet oak are shown in figure 2. The Table Mountain pine chronologies are fairly robust as the number of trees sampled ranged from 19 to 49. At the two Tallulah stands, growth peaks in the early 1910's, declines until the late 1920's, accelerates until the late 1940's (Upper Tallulah) or late 1950's (Lower Tallulah), then declines until the present. There is no such pattern at the Big Ridge site. In fact, there is no discernable growth pattern at all for Table Mountain pine at Big Ridge.

Pitch pine and oak chronologies are not as robust as Table Mountain pine chronologies because the number of trees sampled is considerably smaller (3 to 21). Among the sites, radial growth patterns for all three species show little similarity to each other nor do they show much similarity to those of Table Mountain pine.

The Palmer Drought Severity Index for 1895 to 2000 is also shown in figure 2. Short-term droughts (1-3 years) were fairly common during the $20^{th}$ century with especially severe ones occurring in the mid- to late-1920's, throughout the 1930's, mid 1950's, mid 1980's and late 1990's.

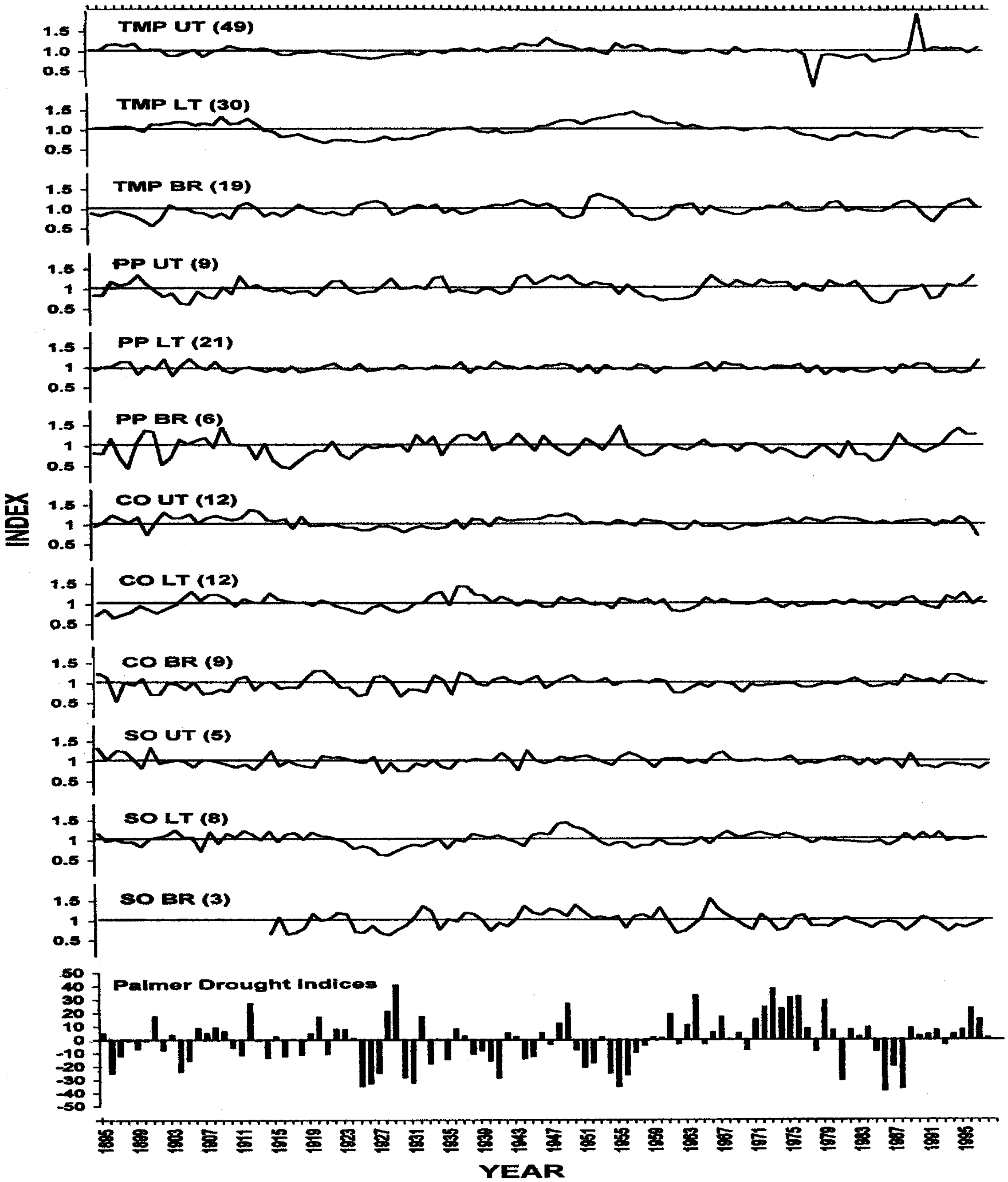


Figure 2—Radial growth chronologies for Table Mountain pine (TMP), pitch pine (PP), chestnut oak (CO), and scarlet oak (SO) and Palmer Drought Indices from 1895 – 2000 for the Big Ridge (BR), Lower Tallulah (LT), and Upper Tallulah (UT) stands in northern Georgia. Numbers in parenthesis indicate sample size.

When compared to species establishment dates in figure 1, drought apparently had little detrimental effect on the regeneration of any of the species.

## DISCUSSION

The establishment dates and radial growth data indicate similar, yet different, histories for the three sites. Prior to 1900, these sites supported a mixture of xeric hardwoods (primarily American chestnut and chestnut oak), pitch pine, and Table Mountain pine. Of these, American chestnut probably dominated with the other species forming a moderate minority. The current density and stocking of chestnut stump sprouts (30 to 50 per acre, 60 to 71 percent stocking) indicate the strong position that species formerly held and were probably sufficient to ensure chestnut domination prior to the blight (Paillet and Rutter 1989). Early settlers and travelers often described this forest mixture in this part of Georgia (Plummer 1975).

In that chestnut-oak-pine forest, pitch and Table Mountain pine were able to successfully reproduce but in different patterns. At Upper Tallulah, Table Mountain pine regenerated sporadically before 1865 and continuously after that date. Chestnut oak and pitch pine regenerated episodically during the same time at this location. At Lower Tallulah, all three species regenerated sporadically during the 1800's while only Table Mountain pine successfully regenerated in discrete episodes at Big Ridge.

Apparently, the pre-1900 disturbance regime was conducive to successful regeneration of Table Mountain pine, especially at the Upper Tallulah site. Given the continuous establishment of Table Mountain pine between 1865 and 1900, the lack of rot in the oldest trees, and a near absence of scars in cross-sections, it does not appear that fire was a severe disturbance agent at this site. At Big Ridge and Lower Tallulah, fire may have been more frequent and/or severe, resulting in the episodic regeneration patterns throughout the 1800's.

However, frequent (2 or 3 fires per decade), low-intensity fire may have occurred in all three sites. Such a fire regime would allow some Table Mountain pine regeneration to persist, encouraging establishment of more seedlings, and not causing widespread bole damage to overstory trees. Frequent, low-intensity fires would also encourage regeneration of oak by creating seedbeds and eliminating fire-sensitive competitors (Barnes and Van Lear 1998, Waldrop and Brose 1999).

In the early 1900's, a major disturbance event occurred at all three sites as evidenced by a drop or complete absence of oak and pine regeneration at that time followed by a tremendous establishment surge for 10 to 15 years. Radial growth trends of Table Mountain pine also show an increase at that time, indicating some type of release event. At Big Ridge, this disturbance was undoubtedly a severe fire that few trees survived. Those that did still carry fire scars and/or internal rot. The two Tallulah stands may have experienced some selective logging instead of fire at that time as they probably had more chestnut and are more accessible than Big Ridge. Logging of chestnut became common in the early 1900's when it became evident that the blight was unstoppable (Keever 1953). Also indicating that a severe fire did not occur at that time, trees predating 1900 are more numerous and usually sound, and fire-sensitive, mesic hardwoods begin to be successfully established.

The next major disturbance was in the late 1920's. By that time the American chestnuts that had been killed by the fire or logged would have sprouted, grown into the pole stage, and were probably expressing canopy dominance. The blight killed these developing stands, releasing the codominant oaks and pines, as evidenced by the radial growth increase in Table Mountain pine starting about 1927, and initiating a surge of oak and pine regeneration. Immediately thereafter, establishment of mountain laurel commenced and since then this shrub has come to dominate the understories in all stands, causing all tree regeneration to gradually wane and eventually cease.

Since then, disturbance in these stands appears to have been minimal. Low-intensity surface fires likely occurred in 1946, 1963, and 1971 in the two Tallulah stands but these events impacted only small areas. An outbreak of southern pine bark beetle probably happened in the early 1950's as evidenced by a surge in hardwood and laurel regeneration but not in pine reproduction.

## CONCLUSIONS

These Table Mountain pine stands are the product of severe disturbance (fire, logging, and the chestnut blight) followed by decades of little disturbance. The role of occasional low-intensity surface fires in pine regeneration prior to 1900 was probably important but clearly identifying that role was not possible given the analytical limitations of this study. The lack of severe disturbance since the 1930's has allowed mountain laurel to become established and spread. These stands will eventually convert almost entirely to mountain laurel thickets with a few scattered overstory trees if this shrub is not controlled. However, even a severe disturbance may not change that outcome if it is a singular event. To restore these stands to a successfully regenerating oak/pine mixture, numerous low- to moderate-intensity disturbances (herbicide, mechanical, and/or prescribed fires) over a decade or more are needed to remove the laurel and prepare seedbeds.

## ACKNOWLEDGMENTS

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# PATTERNS OF SEED PRODUCTION IN TABLE MOUNTAIN PINE

**Ellen A. Gray, John C. Rennie, Thomas A. Waldrop, and James L. Hanula**[1]

**Abstract**—The lack of regeneration in stands of Table Mountain pine (*Pinus pungens* Lamb.) in the Southern Appalachian Mountains is of concern, particularly to federal land managers. Efforts to regenerate Table Mountain pine (TMP) stands with prescribed burning have been less successful than expected. Several factors that may play a key role in successful regeneration are currently being investigated. The purpose of this study was to determine if TMP seed viability and availability varied with tree age, cone age, and season. Seeds were collected in four seasons from 2- to 5-year-old cones of 5- to 76+-year-old trees. Results indicate that for trees 11 years and older, cones collected in the winter had the highest number of seeds and the higher percentage of viable seeds. Young trees, less than 10 years old, had many seed, but viability was poor. The results of this study can used to identify stands with an adequate number of viable seed.

## INTRODUCTION

Researchers and practitioners have assumed that a seed source is always available in serotinous-coned species such as Table Mountain pine (*Pinus pungens*); however, little is known about the specific seed biology of TMP. Table Mountain pine stands of the Southern Appalachians are fire-dependent. In the past, cultural burning practices and lightning-ignited fires provided the necessary disturbance for maintaining these stands. The implementation of fire suppression programs in the early twentieth century has resulted in a subsequent decline of TMP and a shift toward fire-intolerant species. Since the majority of Southern Appalachian TMP is located on public lands, federal agencies have joined together to regenerate TMP with prescribed burning. However, efforts to regenerate stands with prescribed burning have been less successful than expected (Waldrop & Brose 1999).

The objective of this study was to determine if seed viability and availability vary with tree age, cone age, and season in (TMP). Also, differences in the number of cones per tree were evaluated. Information from this study may be used to identify stands adequate numbers of viable seed in addition to suggesting the most appropriate season for burning.

## STUDY AREAS

The first criterion in choosing stands for this study was that TMP be the main component of the stand. Second, several tree age classes ranging from 5 to 75+ years needed to be present. Finally, a sufficient number of closed cones ranging in ages from 2 to 5 years needed to be present on the trees of the various age classes.

Several stands in the Nolichucky Ranger District of the Cherokee National Forest (CNF) met the criterion for tree age classes ranging from 11 to 75+ years. Tree age was determined by extracting increment cores at breast height (4.5 ft.) and counting the annual rings.

Additional stands on the Pickens Ranger District of the Sumter National Forest (SNF) and on the Tallulah Ranger District of the Chattahoochee National Forest (ChNF) were needed to provide trees 5 to 10 years of age. In young stands where tree diameter was too small for coring, trees were cut down to determine age.

## METHODS

### Cone Collection

Cone collection took place in four consecutive seasons, beginning in the fall of 1999 and ending in summer of 2000. One collection was made from each location during each season. Fall months included September, October and November. Subsequent collections for the remaining seasons, winter, spring, and summer included three months for each season.

Sixty-six trees ranging in age from 15 to 148 years (at breast height) were chosen from the three locations in CNF. An aerial lift truck with a 55-foot boom, provided by the U.S.D.A. Forest Service, Southern Research Station, was used for cone collection at the CNF locations.

Forty sample trees ranging in age from 5 to 12 years (at breast height) were chosen from the SNF and ChNF. Access to cones for the younger stands in the SNF and ChNF locations was achieved once trees were cut down.

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**Table 1—Average number seeds per cone by tree age class, season, and cone age in TMP stands in the CNF, SNF, and ChNF.**

| Tree age class | Mean[a] |
|---|---|
| 5 - 10 years | 46.0a,b |
| 11 – 25 years | 51.9a |
| 26 - 50 years | 43.5a,b |
| 51 - 75 years | 41.5b |
| 76+ years | 37.9b |
| **Season Mean[a]** | |
| Fall | 45.9a |
| Winter | 49.8a |
| Spring | 39.2b |
| Summer | 37.5b |
| **Cone age Mean[a]** | |
| 2 years | 38.2b |
| 3 years | 46.0a |
| 4 years | 47.3a |
| 5 years | 47.0a |

[a] Means within each group followed by the same letter do not differ at alpha=.05

A total of 264 cones was expected each season from the 66 sample trees. However, infestations of TMP coneworm(*Diorytria yatesi*) reduced the success of finding sound cones. Collections included only 232 cones (88 percent) in the fall, 206 cones (78 percent) in the winter, 185 cones (70 percent) in the spring, and 160 cones (61 percent) in the summer. Each collection produced increasing evidence of coneworm infestation. There was no sign of coneworm damage in the young sample trees on the Sumter and Chattahoochee National Forests.

This study focused on closed cones 2 to 5 years old. To ensure accuracy, cone age for this study was determined by color, position of whorl on branch, and time of year. In addition, no cones were sampled from broken branches. Once removed from the branch, each cone was placed in a separate paper bag. Tree number, cone age, and location were recorded on the bag.

### Seed Extraction

Following cone collection for each season, bags were placed one layer thick in a drying oven for a minimum of 12 hours at 60°C to allow cones to open. Following heating, bags were removed and stored at room temperature. Seeds were removed from the cones, by turning the cones upside down and knocking it on a hard surface. Seeds were collected and seed wings removed. Seeds were then counted, placed in small envelopes, and labeled for identification.

### Seed Germination

To determine seed viability, a sample of two-thirds of the total number of seeds extracted from each cone was selected for the germination test. For cones containing fewer than three seeds, one seed was selected. The selected seeds from each cone were placed in a covered 100x15 mm plastic Petri dish lined with a 9.0 cm diameter, course filter paper moistened with deionized water. Petri dishes were labeled, sealed with two-inch parafilm to prevent moisture loss, and placed in an incubator and held at a constant temperature of 25°C for 14 days. After 14 days, dishes were removed and opened. Seeds were considered viable if any growth could be seen.

### Statistical Analysis

Each cone collected represented one observation. Percent viability was the number of viable seeds divided by the total number of seeds tested times 100. The total number of seeds extracted from each cone and percent viability per cone was then analyzed with ANOVA using the General Linear Methods procedure in SAS (SAS Institute 1997). Variables tested were tree age-classes, seasons, and cone ages, and interactions among these variables. Means were obtained for tree age-classes, seasons, and cone ages, and tested using Duncan's Multiple-Range test. All statistical analyses were conducted using a 95 percent confidence level.

## RESULTS

### Seed Availability

Significant differences occurred in the number of seeds extracted from a cone by season and also by cone age (table 1). There were no significant interactions of tree age class, cone age, and season. The average number of seeds per cone generally decreased with tree age class. In general, there were two overlapping groups for tree age class: (1) 11-25 years, 5-10 years and 26-50 years; (2) 26-50 years, 51-75 years and 76+ years. The average number of seeds extracted per cone was significantly higher for the winter and fall collections than for the spring and summer collections. Extraction numbers by cone age indicated that seeds were significantly more numerous in 3-, 4-, and 5-year-old cones than in 2-year-old cones.

### Percent Viability

Seed viability significantly varied with tree age classes, seasons, and cone ages. The analysis produced no significance in the interactions of tree age class, cone age, and season. Seed viability was highest for the 76+ years tree age class at 38.6 percent and lowest for the 5–10 year tree age class at 8.8 percent. For the 5-10 year tree age class, seed viability was significantly lower than the other classes. Seed viability for winter and spring collections was significantly higher than viability for fall and summer collections. Viability of seeds collected in the summer was significantly lower than that of the other three seasons. Four and 5-year-old cones did not vary significantly, but had significantly higher viability than did 3- and 2-year-old cones. Viability for 3- and 2-year-old cones did not vary. Four and 5-year-old cones did not vary significantly, but had significantly viability than 3- and 2-year-old cones. Viability for 3- and 2-year-old cones did not vary significantly.

**Table 2—Average percent viability of seed by tree age class, season, and cone age in TMP stands in the CNF, SNF, and ChNF.**

| Tree age class | Mean[a] |
|---|---|
| 5- 10 years | 8.8b |
| 11 - 25 years | 33.3a |
| 26 - 50 years | 32.7a |
| 51 - 75 years | 32.9a |
| 76+ years | 38.6a |
| Season | Mean[a] |
| Fall | 28.1b |
| Winter | 40.0a |
| Spring | 35.4a |
| Summer | 21.2c |
| Cone age | Mean[a] |
| 2 years | 27.3b |
| 3 years | 27.6b |
| 4 years | 38.5a |
| 5 years | 36.7a |

[a] Means within each group followed by the same letter do

## DISCUSSION

Lack of regeneration following prescribed fire in the fire-dependent Table Mountain pine stands led to several questions. The questions focused on in this study were, "Can stands with an adequate and viable seed source be identified?" and "Are there differences in seed numbers and viability as a result of tree age, cone age, and/or the season in which the seeds were collected and germinated?"

### Seed Numbers and Viability

McIntyre (1929) reported that TMP averaged 49.6 seeds per cone with an average viability of 81 percent. McIntyre (1929) was the only published report with which to compare the results. There was no significant difference in the number of seeds per cone from trees 5 to 76+ years old. However, seeds did decrease in number as tree age increased beginning with the 11-year-old trees. The exception to this trend was the 5- to 10-year-old trees whose seed numbers exceed those trees 26 to 76+ years old. Trees in the 5 to 10 year age class were located farther south in latitude than the 11 to 76+ age class trees, and may have produced differences as a result of soil and climate. McIntyre (1929) found that both drought and heavy precipitation could have a greater influence on cone and seed development than age of tree.

Although trees of all age classes produced an adequate number of seeds, there was a significant drop in percent seed viability and the number of viable seeds per cone in trees 5 to 10 years old. As stated earlier, location may be a factor. This could also be a response to fire intervals in the past. Harmon (1982) and Sutherland and others (1993) showed that prior to acquisition by the U.S. Forest Service, fires occurred approximately every 10 to 12 years in some areas of the Southern Appalachians 1993). Although seed numbers in the 5 to 10 year age class are adequate, low viability in this age class may result in poor regeneration if very young stands are burned too frequently. However, periodic fires are necessary to reduce the establishment of hardwoods which out-compete young seedlings.

### Cone Age

The trends for number of seeds per cone and for viability was the same, with 2-year-old cones ranking significantly lower in both categories. Seeds from 3-year-old cones were also significantly lower in percent viability and the number of viable seeds per cone than seeds from the 4- and 5-year-old cones.

This was probably the result of differences in pollenation and other factors in the respective years of cone development. These effects could not be separated because the cones in this study were collected in the same year; that is, 2-year-old cones were initiated in 1998, 3-year-old cones in 1997, and so forth. To separate the effect of cone age from the effect of year would require a multi-year study. This study does suggest, however, that viability does not decrease with time.

### Season

Cones collected in winter and fall produced a significantly higher number of seeds than cones from the spring and summer collections. Percent viability was highest in seeds from the winter collection, but not significantly different from spring. The lowest percent viability and the number of viable seeds per cone occurred in seeds in the summer months. This suggests that although cones ripen in autumn of the second season, seed viability may not peak until winter. Mature cones generally turn brown; however, cone color alone may not be sufficient evidence for maturity. To avoid collecting immature seeds, the manual of *Seeds of Woody Plants of North America* (Shopmeyer 1974) suggests checking ripeness in a small sample of cones from individual trees. A mature seed has a firm white or cream-colored endosperm and a yellow to white embryo that nearly fills the endosperm cavity.

The delayed effects of severe drought can cause reduced production of viable seed. In addition, high temperatures can cause premature opening of serotinous cones. It also reduces the production of viable seeds by desynchronizing pollen release and female strobilus receptivity or by inhibiting germination (Zobel 1969).

As seeds age, viability can be maintained for some time. However, they eventually enter a period of rapid decline during which some seeds completely fail to germinate and grow normally. The differences in viability among seeds of the same age can be related to heterogeneity of individual seeds within a seed lot (Kozlowski 1972). Frequent fire is an important technique to perpetuate the existence of genetic diversity within stands and would allow for regular population turnover (Gibson and others 1990).

## CONCLUSION

To enhance forest health and reduce fuel concentrations, the United States Department of Agriculture and the United States Department of the Interior have established a national program to increase the use of prescribed fire as a management tool. Without periodic fire, it is unlikely that fire-dependent species such as the Table Mountain pine will achieve optimal regeneration.

To achieve success, several factors are needed including adequate seedbed with available moisture and light, fire intervals that do not negatively affect the microbial activity in the soil, and an adequate and viable seed crop. Tree age is not a factor since stands older than 10 years of age provided an adequate seed source.

Although cones did show some difference in their ability to provide adequate viable seed numbers, there would be no way to discriminate among cones of different ages when burning. Further, although the seeds of Table Mountain pine mature in the fall of the second season, winter provided the highest percentage of viable and number of viable seed.

If management of declining populations is to be effective, the development of a prescribed burning plan should consider tree age and season in which burning is implemented to ensure that an adequate and viable seed source is present.

Further investigation into seed biology should be considered. This study was limited to one year and forced to eliminate trees originally selected due to insect damage and drought conditions. Conducting this research over a longer period of time and over a wider area, would better qualify results.

## ACKNOWLEDGMENTS

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# OPTIMAL SEEDBED REQUIREMENTS FOR REGENERATING TABLE MOUNTAIN PINE

**Helen H. Mohr, Thomas A. Waldrop, and Victor B. Shelburne[1]**

**Abstract**—High-intensity, stand replacement fires have been recommended to regenerate stands of Table Mountain pine *(Pinus pungens* Lamb.) because its seeds require mineral soil to germinate and seedlings are intolerant of shade. Recent prescribed fires have resulted in poor regeneration, even though crown fires created seedbeds with abundant insolation and thin duff. This study examined regeneration success over a range of duff depth and shading in a greenhouse. Root lengths were compared over a range of duff depths. Table Mountain Pine seeds germinated and seedlings survived on seedbeds with abundant insolation and thin duff. However, stem density was significantly higher under moderate shade and on duff up to 4 in. thick. Seedling roots were able to penetrate duff depths up to 4 in. These findings suggest that prescribed fires of sufficient intensity to eliminate shade and expose mineral soil are unnecessary to regenerate Table Mountain pine.

## INTRODUCTION

Fire has existed in the Southern Appalachians for thousands of years, ignited both by humans and by lightning. Humans altered the role of lightning by burning outside of the natural fire season of summer. Pyne and others (1996) described the South as "a biotic putty constantly molded and reshaped but kept malleable by chronic burning." Fire exclusion in the modern Southern Appalachians is a result of policies in place on Federal lands for the last 7 to 8 decades and may explain the decline in many plant communities, including Table Mountain pine (*Pinus pungens* Lamb.) (Waldrop and Brose 1999).

Table Mountain pine grows on steep ridge tops and south-facing slopes of the Appalachian Mountains. It ranges from central Pennsylvania to northeastern Georgia. Typically it is found on xeric sites with rocky soils where only a few hardy species are able to survive the harsh environment. Today oaks encroach on these stands, primarily chestnut oak (*Quercus prinus* L.), and hickories. Serotinous cones and thick bark indicate that Table Mountain pine is a fire-adapted species, which needs fire to regenerate.

Past studies indicate that microhabitat plays an important role in seedling survival. Williams and Johnson (1992) noted that seedling emergence and survival was lower on deep litter. Zobel (1969) indicated that extreme fire aids Table Mountain pine reproduction because it destroys competing vegetation and the litter layer. His research suggested that severe fire is necessary for successful Table Mountain pine regeneration. Severe fires kill canopy trees and undergrowth and expose mineral soil (Zobel 1969). Waldrop and Brose (1999) reported opposing results from a study done in northeastern Georgia. They found that the highest fire intensities produced the lowest density of seedlings.

This study compared different duff depth and shade level combinations to determine the best microhabitat for survival. It also determined duff depth and shade level effects on germination, height growth, root development, soil moisture, and survival.

## METHODS

The study was conducted in a greenhouse at Clemson University in Clemson, SC, using a split-plot randomized complete block design. The main plot effect was shade, and the subplot effect was duff depth. Shade levels were 0, 38, 52, and 98 percent and duff depths were 0, 2, and 4 in. Each of the three replications consisted of 4 sets of 24 pots. Each set of 24 pots was randomly assigned a shade level treatment while each pot was randomly assigned a duff depth treatment. This pattern resulted in eight subsamples for each duff depth within each set of 24 pots.

Rectangular PVC boxes were constructed and commercial grade shade cloth was sewn to dimensions to slip over the PVC boxes. These boxes were then placed over each set of 24 pots. Mineral soil and duff (O layer) was gathered from an area that had been burned a few weeks prior on the Andrew Pickens Ranger District of the Sumter National Forest in South Carolina. Soil was placed in 6-in. square pots and either 2 or 4 in. of duff was layered on top of the mineral soil.

Seeds used in the study were gathered from three mature, healthy Table Mountain pines in close proximity on the Tallulah Ranger District in northeast Georgia. Seeds were gathered by cutting the trees down and clipping closed cones from the branches. Cones were then heated at 85 °C for about 20 minutes or until the cones began to open. After the cones cooled and the seeds were shaken out, seed viability was tested in the laboratory. Twenty seeds were placed in five petri dishes lined with moistened paper.

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**Table 1—Soil moisture by duff depth and shade level**

| Treatment level | Soil moisture[a] July | Soil moisture[a] August |
|---|---|---|
| Duff depth (in.) | | |
| 0 | 2.64a | 0.89a |
| 2 | 3.33ab | 2.05b |
| 4 | 4.10b | 2.87c |
| Shade level | | |
| 0 | .57a | .30a |
| Low | 1.97b | .62a |
| Medium | 4.06c | 2.25b |
| High | 6.83d | 4.57c |

[a] Means followed by the same letter within a treatment group are not significantly different at the 0.05 level.

Three replications, 18 days each, indicated a 50-percent germination rate.

The greenhouse study began on May 4, 1999, when 25 seeds were placed in each pot. Pots were watered initially and thereafter watering closely followed the rainfall pattern of the first growing season after a prescribed burn in a Table Mountain pine stand in northeastern Georgia (Waldrop and Brose 1999). Rainfall data came from a nearby weather station in Clayton, GA. Watering occurred twice a week during June, once a week in July, and every 10 days in August.

Soil moisture, germination, seedling height, root length, and seedling survival were measured from May 18, 1999, to September 13, 1999. Soil moisture was measured in each pot in July and August. A soil moisture meter was placed in each pot. The moisture was measured on a scale of 0 to 10 where 0 showed no moisture and 10 was fully saturated soil. Seedling germination and survival were measured weekly. New germinants and dead seedlings were counted and recorded for each pot. Seedling height and root length were measured after 3 months and the tallest seedling in each pot was measured. Roots were extracted from the soil, washed, and measured. Total root length and the length of root in mineral soil by duff depth were recorded.

## RESULTS AND DISCUSSION

### Soil Moisture

Soil moisture was measured to determine the effect of duff depth and shade level as ambient temperature increased and watering became less frequent. In July and August, soil moisture was higher with increased shade and duff (table 1). Soil moisture in July showed a significant difference among all four shade levels. In August there was no significant difference in the 0 and low shade levels, suggesting that medium and high shade levels retain soil moisture by reducing evapotranspiration.

Among duff treatments, in both July and August, soil moisture was highest in 2 and 4 in. of duff. In July the only significant difference in soil moisture was between 0 and 4 in. In August all duff depths were significantly different, suggesting the duff acted as mulch, holding moisture longer. Among all 12 treatment levels (4 shade levels by 3 duff depths) soil moisture was highest under high shade with 4 in. of duff.

### Germination

Germination rates ranged from 63 to 71 percent (table 2). There was no statistical difference in percent germination on different duff depths or under different shade levels. Frequent watering during the germination period allowed abundant germination for all treatment combinations.

### Seedling Height

Seedling height varied little among duff depths, ranging from 3.5 to 3.8 in. (table 3). Although the range in seedling heights was small, those on 4 in. of duff were significantly taller than those on 0 duff and 2 in. of duff.

Shade level had a more pronounced effect on growth, with seedling heights ranging from 3.0 in. under high shade to 4.1 in. under medium shade. Seedlings grown under low and medium shade were significantly taller than those grown under 0 and high shade. Under high shade, seedlings were probably not getting enough sunlight, although available moisture was plentiful. Zero shade provided plenty of sunlight but lower soil moisture and likely reduced height growth. The optimum combination of shade and duff for height growth was low to medium shade with either 2 or 4 in. of duff. This combination provided enough sunlight without drying the soil.

**Table 2—Mean germination by duff depth and shade level**

| Treatment level | Mean germination[a] |
|---|---|
| | *Percent* |
| Duff depth (in.) | |
| 0 | 70.7a |
| 2 | 68.5a |
| 4 | 63.3a |
| Shade level | |
| 0 | 62.6a |
| Low | 67.3a |
| Medium | 69.7a |
| High | 70.6a |

[a] Means followed by the same letter within a treatment group are not significantly different at the 0.05 level.

**Table 3—Seedling height by duff depth and shade level**

| Treatment level | Seedling height[a] |
|---|---|
| | *Inches* |
| Duff depth (in.) | |
| 0 | 3.5a |
| 2 | 3.6a |
| 4 | 3.8b |
| Shade level | |
| 0 | 3.5a |
| Low | 3.9b |
| Medium | 4.1b |
| High | 3.0c |

[a] Means followed by the same letter within a treatment group are not significantly different at the 0.05 level.

**Table 4—Root in mineral soil by duff depth and shade level**

| Treatment level | Root length in soil[a] | Total root length |
|---|---|---|
| | ---- *Inches* ---- | |
| Duff depth (in.) | | |
| 0 | 4.4a | 4.4 |
| 2 | 3.9b | 5.9 |
| 4 | 3.8b | 7.8 |
| Shade level | | |
| 0 | 6.0a | |
| Low | 5.3b | |
| Medium | 3.5c | |
| High | 1.3d | |

[a] Means followed by the same letter within a treatment group are not significantly different at the 0.05 level.

## Root Length

Total root length increased from 4.4 to 7.8 in. as duff depth increased (table 4). This pattern suggests that duff depth partially enhanced root growth as roots grew to reach mineral soil. Past research suggested that postfire duff must be thin so that roots could reach mineral soil (Waldrop and Brose 1999, Williams and Johnson 1992). In this study, however, roots penetrated even the thickest duff (4 in.), and there was no difference in root length in mineral soil for 2 or 4 in. of duff (table 4). Root length in mineral soil averaged 3.9 in.

Root length in mineral soil by shade level was significantly different for all four shade levels. As the shade level decreased, root length increased. Seedlings under high shade were probably allocating greater energy to height growth to reach sunlight and less energy to root growth. The longest roots in mineral soil, 6 in., were in 0 shade.

## Survival

Survival was significantly greater in duff depths of 2 and 4 in. as compared to 0 duff; however, there was no significant difference between the 2- and 4-in. treatments with 25 percent survival (table 5). Among shade treatments, medium shade had significantly greater survival with more than double any other shade level. All shade levels with either 2 or 4 in. of duff had greater survival than with 0 duff (fig. 1). Again, duff acts as a mulch by retaining soil moisture. Survival was second highest under high shade (15.9 percent). In 0 and low shade, seedlings were getting plenty of sunlight, but the lack of shade caused soil to dry. The best survival was with medium shade and either 2 or 4 in. of duff. Duff depth did not seem to matter as long as some duff was in place.

## CONCLUSIONS

Zobel (1969) stated that regeneration persisted in areas where an intense fire had killed canopy trees and almost all the understory. Seedlings persisted especially where erosion had occurred. Therefore, Zobel (1969) suggested that a severe fire is necessary to successfully regenerate Table Mountain pine when there is a well-developed shrub layer. This study may contradict Zobel's findings, suggesting that Table Mountain pine seedlings are able to tolerate more sunlight and duff depth than he reported.

This study showed that medium shade with either 2 or 4 in. of duff was the best treatment combination for successful survival. Medium shade slows moisture loss through evapotranspiration while allowing enough sunlight for successful survival. Seedling roots can penetrate duff up to 4 in., while duff acts as mulch retaining mineral soil moisture for a longer period.

This study indicates that successful regeneration can be achieved with lower intensity and severity fires than once thought. Lower intensity and severity burning produces less risk for loss of control and leaves more duff and litter intact, thereby reducing the chance of erosion occurring on these steep ridge-top slopes. Most importantly, burning at lower fire intensities and severities increases the burning window. High intensity and severity fires are difficult to

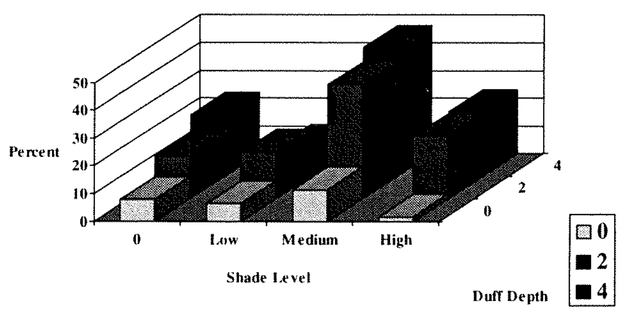


Figure 1—Seedling survival for all combinations of duff depth and shade level.

**Table 5—Percent survival by duff depth and shade level**

| Treatment level | Survival[a] |
|---|---|
| | *Percent* |
| Duff depth (in.) | |
| 0 | 6.8a |
| 2 | 24.0b |
| 4 | 25.5b |
| Shade level | |
| 0 | 15.0a |
| Low | 11.3a |
| Medium | 33.0b |
| High | 15.9a |

[a] Means followed by the same letter within a treatment group are not significantly different at the 0.05 level.

accomplish because of a limited number of suitable burning days each year.


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# CONE CHARACTERISTICS AND SEED QUALITY 10 YEARS AFTER AN UNEVEN-AGED REGENERATION CUT IN SHORTLEAF PINE STANDS

**Kenneth J. Grayson, Robert F. Wittwer, and Michael G. Shelton**[1]

**Abstract—**Cone characteristics and seed quality for 16 released (stand density 14 square meters per hectare) and 16 unreleased (stand density 28 square meters per hectare) shortleaf pine (*Pinus echinata* Mill.) trees were described by d.b.h. class (28, 33, 38, 43 centimeters) and crown position (upper south, upper north, lower south, and lower north). The 38-centimeter d.b.h. class produced significantly heavier cones than other classes. Average cone dry weight for released trees did not differ significantly by crown position, but the lower north crown position produced significantly lighter cones for unreleased trees. Total seeds per cone did not differ significantly between released and unreleased trees, by d.b.h. class, or crown position; the overall average was 46 seeds per cone. Upper crown positions produced a higher percentage of sound seeds per cone (61 percent) than the lower crown positions (50 percent) for both released and unreleased trees. The percentage of sound seeds also differed significantly between released and unreleased trees with the 38- and 43-centimeter d.b.h. classes of released trees producing the highest percentage. Both released and unreleased trees produced significantly more sound seeds per cone in the upper south crown position (31 seeds per cone) compared to the other crown positions (averaging 25 seeds per cone). Seeds from released trees averaged 91 percent germination compared to 85 percent for unreleased trees.

## INTRODUCTION

Requirements for adequate quantities of viable shortleaf pine (*Pinus echinata* Mill.) seeds to naturally regenerate forests has increased interest in the cone producing ability of natural stands (Baker 1992). Flower induction is influenced by at least five factors: nutrient relationships, induction hormones, light conditions, soil moisture, and temperature (Barnett and Haugen 1995). A thinning or regeneration cut could positively affect three of the above variables: moisture, light, and nutrients. Yocom (1971) reported that removing all trees within 9.1 meters of shortleaf pine seed trees significantly increased the number of sound seeds per cone and doubled the average cone production per tree. Studies have found that pine seed quality is higher when seedfall is greatest (Stephenson 1963, Shelton and Wittwer 1996). A study of seed quantity and quality in shortleaf pine cones from two 15 hectare natural stands found 36 total seeds per cone with an average of 17.5 and 14.5 sound seeds per cone for single-tree selection and seed-tree stands, respectively (Wittwer and others 1997).

Dickmann and Kozlowski (1971) found seeds per cone for red pine (*Pinus resinosa* Ait.) to depend on the number of productive ovules, degree of pollination, and ovule abortion, and they concluded that the number of productive ovules was not highly dependent on the number of scales. A study of table-mountain pine (*Pinus pungens* Lamb.) found cone length did not affect the number of viable seeds, and there was no relationship between tree age, seed viability, or cone size (McIntyre 1929). A study on young open-grown Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) found the outer extremities of branches on the upper and middle south side of the crown had more cones and greater seed contents except for the west quarter of the crown (Winjum and Johnson 1964).

We conducted this study to determine if cone characteristics and seed quality in shortleaf pine vary by crown position, tree diameter, and release treatment. A better understanding of these relationships will be useful for selecting trees to retain for seed production in natural stands and will provide indicators for forecasting future seed crops.

## STUDY AREA

The study area was located in the Ouachita National Forest on the Winona Ranger District, Perry County, AR. Before implementation of uneven-aged management, the stand was irregularly-aged with a uniform canopy dominated by shortleaf pine with mixed hardwoods in the mid to lower canopy. Sixteen uneven-aged management plots (0.20 hectare) were established between December 1988 and March 1989 reducing the overstory pine basal area from 27.6 to 13.8 square meters per hectare (Shelton and Murphy 1997). Plots received one of three residual hardwood basal area treatments (0, 3.4, and 6.9 square meters per hectare). Four plots with complete hardwood control were selected for this study. Each of the 0.20-hectare plots was surrounded by an 18 meter buffer zone receiving the same treatment.

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Shortleaf pine site index averaged 17.4 meters at 50 years. Shelton and Murphy (1997) have given a more detailed description of the study area.

## METHODS

### Tree Selection

Sixteen released trees were selected from the buffer zones of four treated plots, and sixteen unreleased trees were selected from the adjacent unharvested pine-hardwood mixed forest. Sample trees were randomly selected from 5-centimeter d.b.h. classes (28, 33, 38, and 43 centimeters). Sample trees with malformed crowns were excluded from selection. The unreleased stand had about 28 square meters per hectare of total basal area with two-thirds in shortleaf pine and the remainder in hardwoods. Sample trees were measured for height, d.b.h., crown length, crown width, and 5-year radial growth increment at stump height.

### Cone Evaluation

Sample trees were felled during the middle of October 1998 when cones were mature but before seed fall. After felling, the crown was measured for total length and was equally divided into upper and lower halves. The crown was further divided into north and south faces creating four crown positions: lower north, lower south, upper north, and upper south. All branches were removed and separated by crown position, providing a complete population of cones for sampling. The four crown positions and four tree d.b.h. classes were considered treatments split between the released and unreleased treatments with four replicates of each treatment. Twenty cones with no visible defects were randomly sampled from each crown position for seed extraction. Very few crown positions failed to produce at least 20 normal cones; all cones were sampled when a shortage occurred. An additional 10 cones per crown position were sampled for dry weight determination. Cone measurements included length, diameter, dry weight, and volume. Cone volume was determined by water displacement. Other cone attributes evaluated were potentially productive scales per cone, total and sound seeds per cone, and percent germination of sound seeds.

Cones were allowed to air dry for 6 weeks and were then tumbled for 25 minutes. Cones were then oven-dried at 35 degrees Centigrade for 48 hours and tumbled for an additional 15 minutes. Most seeds were extracted prior to oven drying, which was a secondary measure to recover any additional seeds. The efficiency of seed extraction was tested by dissecting 80 randomly selected cones after processing; 2.3 seeds per cone were not removed with a coefficient of variation of 63 percent. Potentially productive cone scales, defined as being large enough for two enlarged sound or empty ovules, were counted after all seeds had been removed on 10 of the 20 cones sampled per crown position to determine the potential seed production capacity.

### Seed Evaluation

Before further seed evaluation, wings and other inert matter were removed. A series of float tests were used to separate the empty seeds from the sound seeds. To test the efficiency of this process, 20 floating seeds were sampled from each crown position and cut to verify that they were empty. After cutting 2,460 floating seeds, only 1 percent appeared to be sound. Sound seeds were allowed to air dry for 3 days before storing in a refrigerator at 3 degrees Centigrade.

Following Association of Official Seed Analysts (1978) guidelines, a germination test was conducted using a sample of 200 sound seeds per crown position with four replicates of 50 sound seeds each when ample seeds were available. All seeds were used for quantities below 200. Seeds were soaked for 24 hours at 21.1 degrees Centigrade; after draining, seeds were placed in polyethylene bags and stratified for 28 days at 4.4 degrees Centigrade. After stratification, all replicates were placed into 4.5 x 4.5-centimeter dishes with a substrate of three layers of filter paper. Seeds were equally spaced to prevent the spread of fungi from infected seeds. Two milliliters of de-ionized water was added to each dish at the start of the germination test, and 0.20 milliliter was added every 7 days. Fungicide was applied on the fifth day of the germination test to contain mold spread. Light was provided 8 hours per day with a temperature of 30 degrees Centigrade. The remaining 16 hours per day coincided with a temperature of 20 degrees Centigrade.

Germination counts began on the fourth day and continued daily. Seedlings with radicles half the size of the seeds or

**Table 1—Results of analyses of variance testing the effects of stand density, tree d.b.h. class, and crown position on cone dry weight, productive scales per cone, percent sound seed, sound seeds per cone, and germination percent**

| Source of variation | Cone dry weight | Productive scales per cone | Percentage sound seed | Sound seeds per cone | Germination percent |
|---|---|---|---|---|---|
| | *P-value*[a] | | | | |
| D.b.h. class (D) | 0.033 | 0.292 | 0.521 | 0.206 | 0.113 |
| Stand density (S) | 0.021 | 0.187 | 0.015 | 0.054 | 0.022 |
| DxS | 0.122 | 0.678 | 0.039 | 0.323 | <0.001 |
| Crown position (P) | 0.001 | <0.001 | <0.001 | 0.010 | 0.484 |
| DxP | 0.303 | 0.700 | 0.463 | 0.201 | 0.121 |
| SxP | 0.044 | 0.929 | 0.934 | 0.677 | 0.164 |
| DxPxC | 0.293 | 0.506 | 0.945 | 0.964 | 0.363 |

[a]*P* level is the probability of obtaining a larger F-statistic

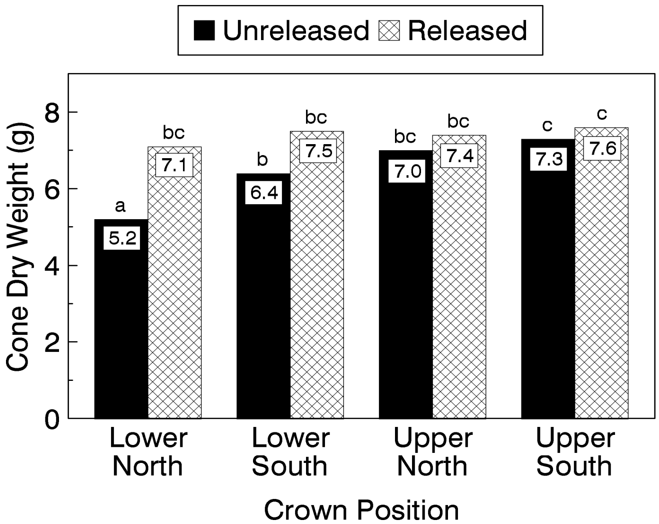


Figure 1—Shortleaf pine cone dry weight for released and unreleased trees by crown position.

longer were evaluated as normal or abnormal according to Association of Official Seed Analysts (1978) standards and removed daily. At the end of testing, seeds that had failed to germinate were cut to determine if they were full or empty. If the percent germination for a replicate deviated by 25 percent or more below the average of all replicates it was omitted from data analysis. Replicates were also omitted when 20 percent or more of the sound seeds were fungi filled. Only 12 replicates out of 450 had to be excluded due to fungi or deviation from the mean percent germination.

### Data Analysis

Mean values for cone characteristics were calculated on a per crown position basis. When crown positions lacked enough cones for dry weight determinations, cones already processed for seeds were used; the weight of missing seeds was estimated from the seed weight of the crown position in question. Percent germination was transformed with the

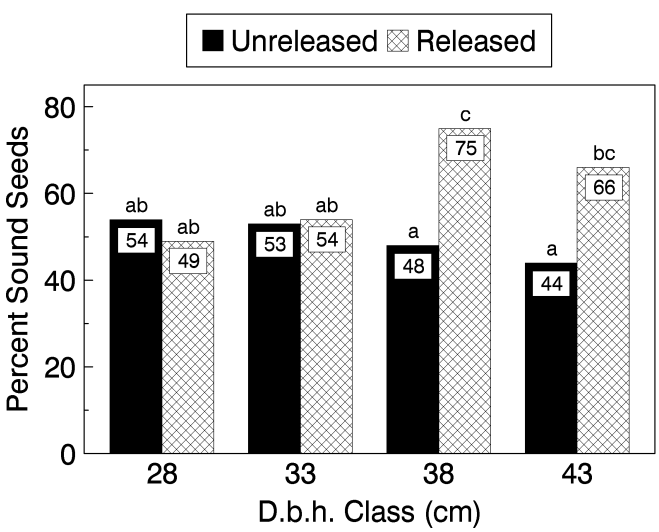


Figure 2—Percentage of sound seed in cones of released and unreleased shortleaf pine by tree d.b.h. class.

arsine square root transformation. The MIXED procedure from the SAS Institute (1997) was used to analyze the data. An analysis of variance for the split-split plot arranged in a randomized complete block design was used to make inferences about cone characteristics by crown positions, d.b.h. class, (split unit treatments) and stand density (main unit treatment). All variables were considered fixed for the mixed model except blocks. Significance was accepted at $\alpha = 0.05$. Multiple mean comparisons were attained by using the LSMEANS statement and DIFF (Fishers Least Significant Difference) and SLICE options (SAS Institute 1997). The SLICE option tests for simple effects; for example, if the interaction of factor A*B is significant, the effect of A for each level of B is tested. Occasionally the relative ranking of all means and their separation may appear contradictory. This may be due to the use of transformed data, multiple standard errors, and missing observations. Multiple standard errors are due to calculations used in the means comparison tests. Means presented in figures are least squares means or estimated means. The only exception is for percent germination, which uses arithmetic means because of the transformation. The arithmetic means and the least squares means will sometimes differ due to an unbalanced design (missing observations).

## RESULTS AND DISCUSSION

### Sample Tree Description

Average age (76 vs. 78 years) and height (20.4 vs. 20.1 meters) of released and unreleased shortleaf pine trees were very comparable (Grayson 2000). Crown width (8.2 vs. 7.3 meters) and length (10.1 vs. 9.1 meters) of released trees averaged slightly greater than the unreleased trees. Released trees contained four more branches per tree with a basal diameter of 2.5 centimeters and greater. Released trees grew 0.51 centimeter more than unreleased trees in radial increment at stump height over the last 5 years.

### Cone Characteristics

Analyses of variance indicated no significant main effects or interactions for cone length, diameter, and volume, which averaged 4.8 centimeters, 2.2 centimeters, and 11.9 cubic centimeters, respectively. Dry weight of cones differed significantly by d.b.h. class, stand density, and crown position, and a significant interaction occurred between stand density and crown position (table 1). Cone dry weight averaged 7.5 grams per cone for released trees and 6.5 grams for unreleased trees. Trees in the 38-centimeter d.b.h. class produced significantly heavier cones at 8.0 grams compared to all other classes. Cone dry weight on released trees did not differ significantly by crown position, but this was not the case for unreleased trees (figure 1). For unreleased trees, the lower north crown position differed significantly from all other crown positions including the released trees.

The number of potentially productive scales indicates potential seed production with each scale capable of containing two ovules. An analysis of variance indicated a significant effect for crown position (table 1); means were as follows: lower north (53 scales per cone), lower south

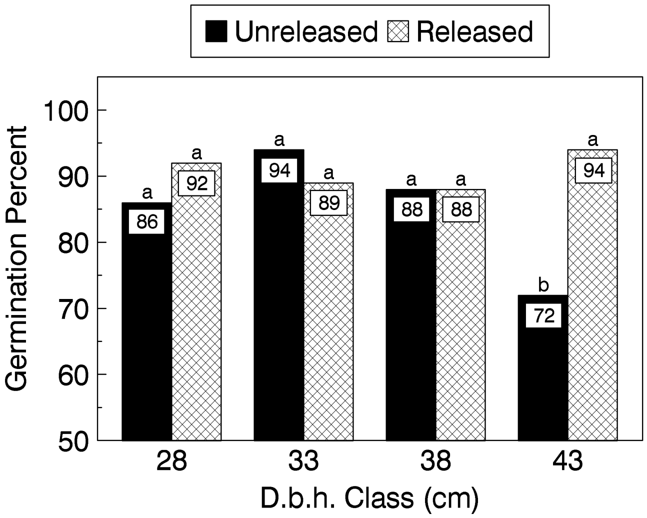


Figure 3—Germination percent of seed from released and unreleased shortleaf pine by tree d.b.h. class.

(55), upper south (56), and upper north (56). The small differences were probably related to differences in cone size by crown position. The total number of seeds per cone was not significantly influenced by tree d.b.h., stand density, or crown position; the overall average was 46 seeds per cone. Despite silvicultural manipulation in the released stand, a gain in total seeds per cone was not apparent.

### Seed Characteristics

The percentage of sound seeds was significantly different for stand density, the interaction of stand density and d.b.h. class, and crown position (table 1). Trees in the released stand produced cones with a significantly higher percentage of sound seeds (61 vs. 51 percent of total). There was a trend for the larger trees to produce a higher percentage of sound seeds in the released stand (figure 2). The ranking and means for percent sound seeds by crown position were as follows: lower north (48 percent) = lower south (51) < upper north (59) = upper south (63).

Differences in sound seeds per cone were nearly significant for stand density ($P = 0.054$); averages were 22 seeds per cone for unreleased trees and 31 seeds per cone for released trees. Wakeley (1954) reported that cones average between 25 and 35 sound seeds during a good seed year for shortleaf pine, which is comparable to our results. Lyons (1956) reported that ovule abortion within the cones of red pine may be associated with nutritional factors. If this is the case, released trees in this study could have received a short-term increase in available nutrients, which should have increased overall tree vigor. The reduction in sound seeds for unreleased trees could be due to carbohydrate deficiencies or self-pollination, since both released and unreleased trees produced approximately the same number of total seeds per cone. Reduced air movement in unthinned stands might hamper pollen cloud dispersal and lead to increased self-pollination and embryo abortion.

Crown position was also significant for sound seeds per cone, and means were ranked as follows: lower north (23 sound seeds per cone) = lower south (26) = upper north (26) < upper south (31). According to Perry and Coover (1933), shortleaf pine cones from the top of the crown produced the most viable seeds (24 seeds per cone) followed by the middle crown (20), and finally the crown base (18). The greater sound seed yield in the upper south crown position is probably due to greater carbohydrate production where light levels are higher and growth is more vigorous when compared to other crown positions.

No significant differences in seed weight were found in our study. Dewinged sound seeds per gram ranged from 68 to 132 for released trees and 66 to 147 for unreleased trees, averaging 99 and 95 sound seeds per gram, respectively. Wakeley (1954) reported cleaned and de-winged shortleaf pine seeds average 106 seeds per gram with a range from 80 to 138.

Analysis of variance for germination of sound seeds indicated a significant main effect for stand density and a significant stand density by d.b.h. class interaction (table 1). Seeds from released trees averaged 91 percent germination compared to 85 percent for unreleased trees. Unreleased trees in the largest d.b.h. class (43 Centimeter) exhibited significantly lower seed germination than other size classes for both released and unreleased trees (figure 3). Cone production of trees in this class was low (Grayson 2000), and a positive correlation between cone and seed production and germination percent has been reported (Shelton and Wittwer 1996).

## CONCLUSIONS

Cone length, diameter, and volume did not vary significantly by stand density, tree d.b.h., or crown position. Cone dry weight differed significantly between released and unreleased trees. Cone weight also differed significantly by tree d.b.h. class with the 38 centimeter d.b.h. class trees producing heavier cones compared to all other classes. The lower north crown position produced significantly smaller cones by weight compared to all other crown positions. The number of potentially productive scales per cone varied significantly by crown position with the upper north position produced significantly greater numbers. The lower north crown position produced significantly fewer potentially productive scales than all other crown positions. Overall, the differences in cone scale numbers by crown position were small and may not have silvicultural importance.

Percentage of sound seeds per cone differed significantly by stand density, the interaction of density and tree d.b.h., and crown position. The released trees in the 38-centimeter d.b.h. class and larger produced significantly greater percentages of sound seeds when compared to the lower diameter classes and unreleased trees. No significant difference was detected between diameter classes for unreleased trees. For released trees, the general trend was for higher sound seed percentages in the upper crown, with increasing tree diameter. Percentage of sound seed tended to decrease with increasing diameter for unreleased trees. Results for percentage of sound seed suggest that selecting larger diameter released trees, at least 36 centimeters in d.b.h. or greater, will increase seed quality. In addition, released trees produced on average 9 more sound seeds per cone than unreleased trees. The upper south crown position produced significantly more sound seeds per cone than other crown positions by 5 to 8 seeds per cone. Germination of seeds was not significantly affected by crown position or stand density, indicating that germination is consistent within the crowns of released and unreleased shortleaf pine.

The reduction in stand basal area to 14 square meters per hectare, the recommended stocking level in uneven-aged stands, had a pronounced effect on seed production within the stand 10 years later. Enhanced seed production is important to the success of uneven-aged management because regeneration depends on seeds produced by retained trees. Most seeds produced in this stand were on trees with d.b.h. greater than 35 centimeters. Thus, we recommend that maximum diameters used for regulating the stocking and structure of uneven-aged stands be over 35 centimeters. More seeds were produced in the upper canopy. Thus, forecasting systems relying on cone counts or ratings should focus on this portion of the canopy.

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# DO CONES IN TOPS OF HARVESTED SHORTLEAF PINES CONTRIBUTE TO THE STAND'S SEED SUPPLY?

**Michael G. Shelton and Michael D. Cain[1]**

**Abstract--**Because success of natural regeneration strongly depends on a stand's seed supply, we conducted a study to determine the potential contribution of cones in the tops of harvested shortleaf pines (*Pinus echinata* Mill.) if trees were felled after seed maturation but before dispersal was complete. Closed cones, collected in October 1998, were stored in wire cages with periodic removals over the following 9 months to determine the number and viability of extracted seeds. Storage sites were an opening in a seed-tree stand and a closed-canopy pine-hardwood stand. Of the initial average of 30 viable seeds per cone, 93 percent had dispersed in the open site and 83 percent in the closed-canopy stand by the end of February 1999, which is considered the end of the normal dispersal period from cones on standing trees. By May, virtually all viable seeds had dispersed from cones in both sites. Results indicate that cones in tops of trees cut during the 2-month period after seed maturation can make an important contribution to the stand's seed supply, especially in reproduction cutting methods where most of the trees are harvested.

## INTRODUCTION

Because of lower establishment costs, natural regeneration is a viable option for shortleaf pine (*Pinus echinata* Mill.) that appeals to many landowners, and about two-thirds of the pine stands in the southeastern United States originated from natural seedfall (USDA Forest Service 1988). Most natural regeneration methods rely on retained trees to produce an adequate seed supply for regeneration. However, trees felled during reproduction cutting may also potentially contribute to the seed supply if felling took place after seed maturation but before complete dispersal. Wakeley (1954) recommended starting in mid-October when collecting shortleaf pine cones for seed extraction. However, Barnett (1976) reported that cones of other southern pines, such as loblolly pine (*P. taeda* L.) and slash pine (*P. elliottii* Engelm.), can yield viable seeds when collected 2 to 3 weeks before recommended dates, suggesting that shortleaf cones may yield viable seeds as early as late September. Shortleaf pine seed dispersal from standing trees is about 50 percent complete by late November and 90 percent complete by the first of January (Wittwer and Shelton 1992). Trees felled in reproduction cutting during the 2-month period from late September to late November have the potential to make a substantial contribution to the stand's seed supply if viable seeds disperse from cones in felled tops. Seeds from tops of cut trees would likely be most important to regeneration success in reproduction methods that remove most of the stand's trees, such as the seed-tree method or small clearcuts.

Although seed dispersal from shortleaf pine trees has been the subject of numerous studies (Stephenson 1963; Wittwer and Shelton 1992; Shelton and Wittwer 1996), we are aware of no earlier investigation of shortleaf pine seed dispersal from cones in tops of felled trees. Objectives of the study were: (1) to determine the potential for cones in the tops of felled shortleaf pine trees to contribute to the stand's supply of viable seeds and (2) to determine the possible fate of seeds dispersed during the growing season when cold, moist stratification that normally promotes germination would not occur.

## METHODS

### Study Area

The study was located on forest lands of the School of Forest Resources, University of Arkansas at Monticello. The study site is in the West Gulf Coastal Plain at 91 degrees 46 minutes West longitude and 33 degrees 37 minutes North latitude. Elevation is 98 meters with a rolling topography. The soil is a Sacul loam (clayey, mixed, thermic, Aquic Hapludult), a moderately well-drained upland soil with a site index of 21 meters for shortleaf pine at 50 years (Larance and others 1976). The growing season is about 240 days with seasonal extremes being wet winters and dry autumns. Annual precipitation averages 134 centimeters.

Two sites were located for cone storage. The closed-canopy site was located in a mature loblolly/shortleaf pine-hardwood stand. Basal area in trees $\leq$ 9.0 centimeters d.b.h. averaged 25.7 square meters per hectare for pines and 6.4 square meters per hectare for hardwoods; basal area was 2.8 square meters per hectare in trees  9.0 centimeters d.b.h. Light intensity at 1.37 meters in height

[1]Research Foresters, USDA Forest Service, Southern Research Station, Monticello, AR 71656-3516, respectively.

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averaged 7 percent of full sunlight at noon during a clear summer day, and the canopy exerted 97 percent ground coverage. The open site was in a 20-meter by 20-meter cleared area within a pine seed-tree stand with approximately 10 sawtimber-sized trees per hectare. This area intermittently received shadows from adjacent trees during the winter months but was mostly in full sunlight during the summer. The open site was 0.4 kilometers from the closed-canopy stand.

## Field Procedures

Closed cones were collected from recently harvested shortleaf pines in a mature sawtimber stand in northern Louisiana (October 13, 1998) and a similar stand in southern Arkansas (October 26, 1998). About five tops were sampled in each stand. Immediately after collection, cones were transported to the two study sites and placed in storage frames designed to simulate logging tops but also to provide protection of cones and seeds from predators. The storage frames were 0.5-meter square and made of 1.3-centimeter mesh galvanized hardware cloth. They were held 0.5 meter above the forest floor by legs constructed of 0.6-centimeter diameter steel. This arrangement allowed wind movement around the frame, which we felt was representative of small branches in the top of a felled tree. A top constructed of 0.35-centimeter mesh hardware cloth covered each frame. Cones were attached to the inside surface of the top by intertwining cone-bearing branches through the hardware cloth. Cones were oriented in a downward angle that averaged 45 degrees. Ten cones from each stand were attached to each storage frame’s top. The 16 frames at each location provided for up to four removals from field storage with four replicates. The first removal was scheduled for late winter 1999, but subsequent removals were based on observed results. Before seed extraction, cones were always removed from storage when closed; if required, cones were gently sprayed with water the night before removal to cause closure.

To provide field validation, additional cones were sampled in early March 1999 from shortleaf pine tops within a logged area about 0.4 kilometer from the open study site. This mature loblolly/shortleaf pine stand was lightly thinned during late September 1998.

To determine the possible fate of seeds dispersed later than normal, we deposited packets of seeds on the soil surface in the closed-canopy stand and the open site bimonthly beginning in April 1999 and continuing through October 1999. Seeds came from the cones collected in October 1998. After hand dewinging, filled seeds were separated from void seeds and debris by floating in a water bath for 4 hours and collecting the sinking (filled) seeds. Packets were made by uniformly spacing 40 seeds between two pieces of fiberglass window screen that were held in place by two pieces of 1.3-centimeter mesh hardware cloth while in field storage. The packets were intended to protect seeds from predation and to isolate seeds for reduced contamination from pathogens. Each packet measured 14 by 15 centimeters. There were 10 packets for each of the four bimonthly placements; four packets were placed in a prepared seedbed at the open and closed-canopy locations, and two packets were used for germination tests at each time of placement. Packets were stored in a National Weather Service instrument shelter located in the open site from November 1998 until placed on prepared seedbeds. Beginning in April 1999, packets were removed from the shelter bimonthly and placed on an exposed mineral soil surface; then finely ground surface soil from the area was sprinkled on packets until the seeds were lightly covered. Packets were periodically inspected after heavy rains, and soil was added as needed to keep the seeds lightly covered. Each seedbed area contained four packets representing a placement and was completely enclosed within 1.3-centimeter mesh hardware cloth to prevent predation.

To determine the natural pattern of opening and closing of cones, we randomly selected two groups of cones that matured in 1998 and placed them in the storage frames. The percentage openness of each cone was visually assessed just about daily from mid-May through June 1999. To determine cone temperature, a thermometer was inserted into a hole drilled in the base of a test cone and read after stabilization. Readings were also taken of the air temperature in a standard National Weather Service instrument shelter in the open site.

## Laboratory Procedures

After removal from field storage, the 20 cones representing each replicate were allowed to air dry in cloth bags for several days until open. Seeds were then extracted by vigorously tumbling cones in a 20-liter plastic bucket. Cones were then lightly heated (33 degrees Centigrade) in a forced-draft oven for 24 hours and a second extraction was made. This process was repeated one additional time. About 90 percent of the seeds were obtained from the first extraction. Seeds were dewinged by hand. After counting, a germination test was conducted by using a subsample of seeds randomly drawn from each replicate. When ample seeds existed, the subsample was either two cups of 50 seeds each or one cup of 75 seeds. When the number of seeds declined below 75 per replicate, all seeds were used in the germination tests.

Test seeds were placed on moist, sterile sand in 10- by 10-centimeter plastic cups and stratified for 30 days at 4 degrees Centigrade. The 30-day germination test was conducted under 10 hours of full-spectrum fluorescent light and 14 hours of dark in accordance with published guidelines (Wakeley 1954). Temperature in the germination room was at 21 degrees Centigrade. A seed was considered to have germinated normally when the seed coat lifted off the sand. A designation of abnormal germination was based on guidelines described by Wakeley (1954). Seeds with fungi were removed immediately to reduce contamination; a cut test was conducted to determine if seeds were full or void (Bonner 1974). At the end of each germination test, a cut test was conducted on all ungerminated seeds; full seeds were classified as being decayed or potentially sound. A seed that germinated normally within the 30 days was considered viable; any full seed that did not germinate normally was considered nonviable.

In February 2000, all packets were removed from field storage, opened, and inspected to count the number of

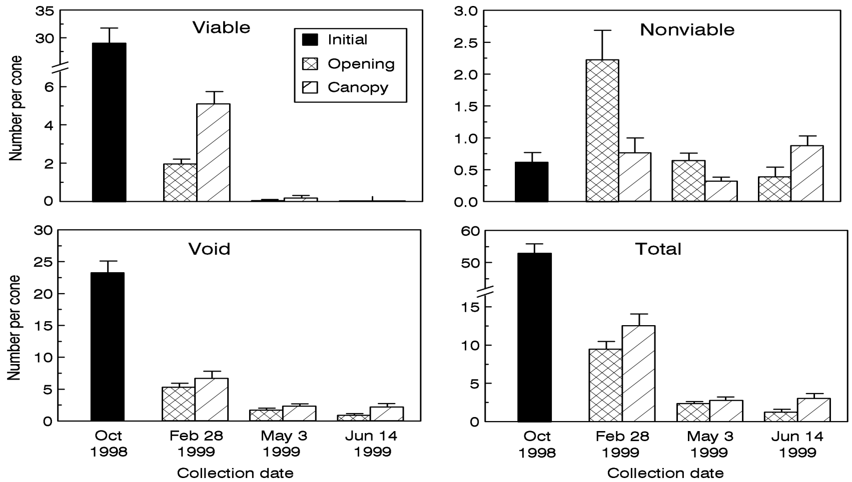


Figure 1—Number and viability of seeds (plus one standard error) observed over a 9-month period during field storage of shortleaf pine cones in an open site and a closed-canopy stand in southeastern Arkansas.

previously germinated seeds based on remnants of a radicle or a split seed coat. A germination test was conducted on all ungerminated seeds as previously described, except that stratification was reduced to 15 days.

### Statistical Analysis

The homogeneity of treatment variances was determined by Bartlett's test (Steel and Torrie 1980). When the hypothesis of homogeneity of variance was rejected at $\alpha \leq 0.05$, data were square-root transformed, which provided homogeneity. Analysis of variance was conducted for a completely randomized, split plot in time and space. A split-plot design was used because each storage location and each time interval was singular. All factors were considered fixed. Replicates were considered the germination results of seeds extracted from the samples of 20 cones or from the 40-seed storage packets. Significance was accepted at $\alpha = 0.05$.

## RESULTS AND DISCUSSION

### Seed Dispersal

The shortleaf pine cones contained an average of 30 viable seeds per cone in October 1998 when they were fully mature (figure 1). This number is typical of years with good seed crops (Wakeley 1954). By late February 1999, viable seeds in the cones had declined by 93 percent in the open site and 83 percent in the closed-canopy stand, and the difference between the two areas was significant (table 1). Seed dispersal from standing shortleaf pines is normally considered complete by the end of February (Wittwer and Shelton 1992). Most of the viable seeds were apparently dispersed because there was no large increase in the number of nonviable seeds over this period.

The viable seeds present in late February (2 seeds per cone in the open site and 5 seeds per cone in the closed-canopy stand) were virtually all dispersed during early spring because few remained in May (<0.2 seed per cone in both the open site and closed-canopy stand). Most of the viable seeds were apparently dispersed because nonviable seeds did not increase over this period. Void seeds showed a similar decline over time as with viable seeds. Our results suggest that void seeds were retained to a greater degree than full seeds (viable and nonviable); void seeds represented 53 percent of the total seeds present in October 1998 but increased to an average of 72 percent in May and June 1999.

**Table 1—Analysis of variance for the number of retained seeds in shortleaf pine cones over a 9-month period of field storage in an open site and a closed-canopy stand in southeastern Arkansas**

| Source of | | Viable seeds | | Nonviable seeds | | Void seeds | | Total seeds | |
|---|---|---|---|---|---|---|---|---|---|
| variation[a] | df [b] | MSE[c] | P>F | MSE[c] | P>F | MSE[c] | P>F | MSE[c] | P>F |
| Location | 1 | 0.72 | <0.01 | 0.18 | 0.16 | 0.69 | 0.03 | 0.96 | 0.02 |
| Error I, RxL | 6 | 0.03 | | 0.07 | | 0.08 | | 0.10 | |
| Time | 2 | 7.33 | <0.01 | 0.54 | 0.01 | 3.52 | 0.01 | 8.56 | <0.01 |
| Error II, RxT | 6 | 0.04 | | 0.05 | | 0.08 | | | 0.08 |
| LxT | 2 | 0.41 | <0.01 | 0.48 | <0.01 | 0.06 | 0.41 | 0.13 | 0.20 |
| Error III, RxLxT | 6 | 0.02 | | 0.03 | | 0.06 | | | 0.06 |

[a] Location (L), replication (R), and time (T).
[b] Degrees of freedom (df).
[c] Mean square error (MSE) for square root transformed data.

The difference in dispersal pattern between the closed-canopy stand and the open site can be explained by differences in environmental factors, such as wind, temperature, dew, frosts, and humidity. These factors affect the drying of cones and thus the rate and degree of opening and closing. These factors also affect the environmental stresses that seeds are subjected to within cones. In May and June 1999, we observed that cones in the open site took an average of 2 days to open fully following a substantial rain (over 2 centimeters), while those in the closed-canopy stand took 6 days. Cones in the open site closed slightly during nights with heavy dew but fully reopened by midmorning of the following day. Dew did not visibly affect cone closure beneath the closed canopy. During midday, the temperature of cones in the open site averaged 7.5 degrees Centigrade higher than air temperature, while those in the closed-canopy stand were 2.2 degrees Centigrade below the open site's air temperature. The harsher environment of the open site resulted in a more rapid decline in seed viability. Although seeds initially had a 98 percent germination rate, germination of full seeds had declined to 87 percent by February 1999 in the closed-canopy stand and only 47 percent in the open site ($P<0.01$). By May and June 1999, germination of full seeds declined to an average of only 14 percent with no significant difference between the two sites ($P > 0.05$). Cain and Shelton (1997) reported a similar decline in viability for shortleaf pine seeds under field storage. There may be little operational significance of the slower decline in seed viability in the closed-canopy stand, as shade-intolerant shortleaf pine seedlings do not survive for long under such conditions. However, there may be microsites within an opening, such as in the shelter of tops or coarse woody debris, that could provide similar levels of protection.

### Field Validation

To determine if the results in our protected storage frames were similar to that found in the field, we conducted additional cone sampling in nearby shortleaf pine stands that had been thinned during late September 1998. The initial base of viable seeds was not known but should have been similar to that of our study because the cones were from the same year. The number of viable seeds in early March 1999 for the thinned stand (9.1 seeds per cone) were very similar to that found in February in our study (5.1 seeds per cone in the closed-canopy stand). The night before the early March collection, a severe rain and wind storm broke the crowns or collapsed about 20 shortleaf pine trees in the stand that was being sampled for cones in logging tops. We collected current-year cones from those trees and confirmed the expected difference in dispersal pattern between standing trees and tops: 0.4 viable seed per cone from the storm-damaged trees compared to 9.1 seeds per cone from the tops ($P = 0.03$). The different seed dispersal pattern from cones of standing trees versus tops of felled trees undoubtedly reflects agitation and drying by the wind, both of which would affect cone openness. Cain and Shelton (1997) reported that a few pine seeds are held so tightly within cones that they may not be dispersed under normal circumstances.

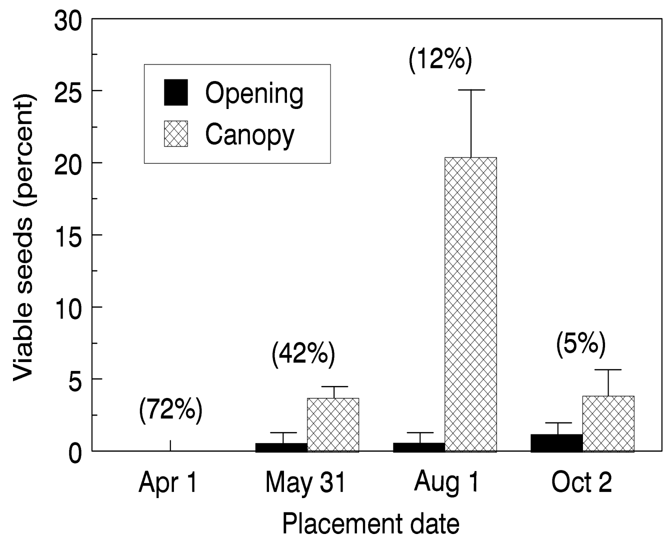


Figure 2—Viable shortleaf pine seeds (plus one standard error) at the end of field testing (February 2000) from packets that had been stored in the open site until placed on mineral soil seedbeds during 1999. The number in parentheses above each bar cluster is the percentage of viable seeds from a subset of packets that were tested for germination at the time of placement.

### Seed Fate

Our results indicate that, in a good seed year, 2 to 5 viable seeds per cone could potentially be dispersed from tops after late February if shortleaf pines are felled after seed maturation but before dispersal is completed. Seeds dispersed outside of the normal pattern exhibited from standing trees would not receive the cool, moist stratification that promotes germination. To determine the possible fate of these seeds, seeds extracted from the October 1998 cone collection were placed into packets and were stored in a weather instrument shelter (open site only) awaiting periodic placement in prepared seedbeds. At the time of placement, seed viability declined linearly during the summer, averaging 72 percent for the placement on April 1 and 5 percent on October 2 ($P \leq 0.01$). These results generally agree with the decline in viability that was observed in the stored cones, suggesting that the seeds in the packets accurately represent seeds in cones that potentially could be dispersed.

All the seeds of the April 1999 placement either germinated or died as there was no germination when tested after removal in February 2000 (figure 2). When inspected in February 2000, 76 percent of the seeds from the April 1999 placement had remnants of radicles or had split seed coats. Subsequent placements during the summer and early autumn indicated potential carryover of viable seeds to the next growing season of about 1 percent in the open site and 4 to 20 percent under the closed-canopy stand ($P = 0.01$). The reason for the apparent anomaly in data for the August 1 placement, where germination appeared to increase through time, was not known. The higher potential carryover rates of pine seeds under the closed canopy probably reflected a less harsh environment than in the open site.

## CONCLUSIONS

From the standpoint of natural regeneration, the importance of seeds dispersed from cones on felled tops is greater when more of the stand is cut than is retained; thus the potential is greatest in seed-tree stands and in small clearcuts. Our study showed that shortleaf pine cones in tops from an early autumn harvest could potentially disperse up to 93 percent of their viable seeds in time to germinate during the spring. Thus, the potential contribution of tops to a stand's seed supply is large. In addition, these seeds are probably dispersed close to the tops, where regeneration is difficult to obtain because the seedling-to-seed ratio is low (Grano 1949, Shelton and Murphy 1999). The contribution of seed-bearing cones in tops of felled trees is probably more important for regeneration during average seed crops than in good seed crops. Dispersal of seeds from cones in tops of felled trees appears to be enhanced by exposure to sunlight which promotes the drying and opening of cones. However, seed dispersal from cones in tops is prolonged when compared to that of standing trees. Up to 20 percent of the seeds dispersed from cones during the summer could potentially carry-over to the following growing season.

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